

INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES

Leslie J. Williamson

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Cambridge 39, Massachusetts

May 23, 1955

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the regulations of the Faculty,
I submit herewith a thesis entitled "Initial Elastic
and Frictional Behavior of Metal Interfaces," in partial
fulfillment of the requirements for the degree of Master
of Science (without specification).

Respectfully yours,

Leslie J. Williamson
Lieutenant, U.S. Coast Guard

RESEARCH INSTITUTE IN TECHNOLOGY

Cambridge 32, Massachusetts

May 17, 1957

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the regulations of the Faculty,

I submit herewith a final revised doctoral thesis

and "Final Report on the Research of the Doctoral Candidate," in partial

fulfillment of the requirements for the degree of Master

of Science (Doctoral Dissertation).

Respectfully yours,

Leslie A. Williamson

Department of Chemistry, U.S. Coast Guard

INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES

by

LESLIE J. WILLIAMSON
Lieutenant, U.S. Coast Guard
B.S., U.S. Coast Guard Academy
(1945)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
(without specification)

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
(1955)

Signature of Author
Department of Naval Architecture and
Marine Engineering, May 23, 1955

Certified by
Thesis Supervisor

Accepted by
Chairman, Departmental Committee on Graduate Students

W626

INITIAL BLASTING AND EXPLOSIVES
RESEARCH OF METAL INDUSTRIES

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Lieutenant, U.S. Coast Guard
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(1933)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
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Department of Naval Architecture and
Naval Engineering, May 23, 1933

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Chairman, Departmental Committee on Graduate Studies

INITIAL ELASTIC AND FRICTIONAL
BEHAVIOR OF METAL INTERFACES

Leslie J. Williamson

Lieutenant, U.S. Coast Guard

Submitted to the Department of Naval Architecture
and Marine Engineering on May 23, 1955, in partial
fulfillment of the requirements for the degree of
Master of Science

ABSTRACT

The object of this thesis is to investigate the reported existence of abnormal elastic effects in metal interfaces. In conjunction with this work, the initial frictional behavior at the metal interfaces was observed.

The method of investigation selected employed hollow cylindrical specimens composed of two mating parts placed end on end. The experimental apparatus utilized a combination of optical and mechanical means of measuring small angles of twist in the specimen. Various metals were tested under different conditions of normal load and surface finish.

Excellent conformity between observed values of twist and those predicted by elastic theory was achieved. The experimental results did not show any indication of excessive elastic angles of twist.

Investigation of the initial frictional behavior of the metal interfaces indicated that the value of the friction coefficient increased with incremental changes in the observed slip until the range of normally expected values was attained. In this range the curve flattened out and free sliding resulted.

In view of the results of this investigation, it is believed that the reported abnormal elastic conditions were the result of inaccuracies in the experimental method, and that further investigation along this line is not warranted.

Thesis Supervisor: Brandon G. Rightmire

Title: Associate Professor

INITIAL CLASSIC AND INVESTIGATIVE
STUDYING TO SOCIAL INVESTIGATIVE

James E. Williams
Investigator, U.S. Social Service

Investigation to the Department of Social Investigation
and Social Investigation to the U.S. Social Service
Investigation to the Department of Social Investigation
Investigation to the Department of Social Investigation

ABSTRACT

The object of this study is to investigate the various
aspects of the social service in the United States.
In connection with this study, the social service
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To Professor Brandon G. Rightmire, who kindly consented to supervise this thesis, I wish to express my sincere appreciation of his helpful suggestions and encouragement during the course of the research.

I wish also to thank the members of the Lubrication Laboratory for their co-operation.

Finally, to Bertha Hornby, who typed the thesis, go my thanks for her careful work.

MEMORANDUM

TO: Professor Richard B. Lippman

FROM: [illegible]

SUBJECT: [illegible]

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I. INTRODUCTION

In a thesis,⁽¹⁾ Coyle and Stromberg reported the existence of abnormal elastic effects in metal interfaces. As a result of their work, they concluded that the asperities in steel interfaces contribute materially to the elastic twist. The elastic twist due to an interface appeared to decrease with increase in normal stress for a given value of maximum tangential stress. They also found that the effect of surface finish was affected by normal stress, in that a transition range existed for normal stress. This transition range separated the regions where elastic twist increased or decreased with the degree of surface finish. This appears to be a virgin investigation of elastic effects in metal interfaces, as a survey of the literature failed to disclose any previous work along this line.

Tomlinson, Thorpe, and Gough,⁽²⁾ in a paper on fretting corrosion, reported that surfaces in contact under normal and tangential stresses have a comparatively high degree of tangential elasticity. "The surfaces appeared to yield under tangential stress in an elastic manner by an amount which may be many times greater than the smallest slip it is hoped to detect." This made their problem of measuring slip extremely difficult. In the second phase of this investigation, this problem was encountered where the displacements measured were of the same order of magnitude as the depth of the asperities

C. DISCUSSION

In a paper,⁽¹⁾ Taylor and I previously reported the results of chemical analysis of various effects in metal lattices. In a recent paper,⁽²⁾ they concluded that the separation in which the lattice structure is affected in the elastic limit. The chemical analysis was in an intermediate stage of development in metal alloys for a given value of mechanical properties. They also found that the effect of various lattice defects on metal alloys, in that a considerable amount of the lattice structure is affected by various defects. This separation stage is observed in the lattice where elastic limit is reached or exceeded. The lattice of various metals. This appears to be a typical example of elastic effects in metal lattices, as a comparison of the literature failed to disclose any previous work along this line.

Frederick, Taylor, and Gage,⁽³⁾ in a paper on "The Elasticity of Metals," reported that various in metals under normal and high pressure have a comparatively high degree of elasticity. The authors reported in their paper that the lattice structure in an elastic manner by an amount which may be very small greater than the amount of the lattice in which it is found. This work was a problem of measuring the elasticity of metals. In the case of this investigation, the authors were concerned with the displacement of the lattice of the metal at various stages of the lattice.

in the metal interfaces. The first objective of this investigation was the development of a test apparatus and an experimental procedure of sufficient sensitivity and accuracy so that the existing discrepancies between calculated theoretical and observed values of elastic twist would be eliminated or rationalized. Various methods of measuring elastic twist in a specimen were considered, as discussed in Appendix A.

The second phase of this work was a by-product of the original investigation. After extensive examination of the elastic effects at metal interfaces under various conditions of load and surface finish, it was decided that a study of the frictional behavior would be both interesting and valuable.

in the next instance. The first objective of this investigation was the development of a test apparatus and an experimental procedure to establish sensitivity and accuracy in measuring the relationship between selected physical and chemical properties of various soils. Various methods of measuring physical properties were considered, as discussed in Appendix I.

The second phase of this work was a by-product of the physical investigation. After extensive consideration of the physical effects of soil, interest was aroused in the possibility of using the physical effects as a means of determining soil properties. It was decided that a study of the physical properties would be both interesting and valuable.

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II. PROCEDURE

The test apparatus used in this work is illustrated in Figures I, II, and III.

The tubular specimens tested were machined from the following materials: (1) AISI C-1018, cold-finished, open-hearth, low-carbon steel; (2) AISI A-4140, heat-treated, stress-relieved, medium-carbon alloy steel; (3) hard-drawn, electrolytic, tough pitch copper rod; (4) 2S Aluminum.

The specimens were reamed out to an inside diameter of 0.191"; then turned down to 0.236" outside diameter. The test specimens were cut into two halves, each one inch long. A single two-inch specimen was made for each material, and used as a control specimen. The observed deflections of the control specimen (ψ_c) were compared with the computed deflections (ψ_e) as predicted by elastic theory, thus providing a check of the accuracy of the test runs. The effect of the interface could be determined by a comparison of control-specimen runs with test-specimen results.

The upper and lower halves of the test specimen are mounted as shown in Figure III. The contact surfaces were lapped to the desired finish with emery polishing paper of varying degrees of roughness. The specimen was clamped in a vee-type block during the polishing process, to insure that the test surfaces were ground perpendicular to the specimen axis. The specimens were carefully cleaned both before and after the

polishing process. (Reagent acetone was used as cleaning solvent.)

Two double-ended indicator arms were used, one on either side of the interface. Each arm was constructed with two 12" lengths of Type 321 stainless-steel tubing having 1/8" outside diameter and 0.005" wall thickness. The indicator arms were fastened to the specimen by a collar, as shown in Figure III. The cone-pointed set screws were used to obtain a knife-edge line from which the twist was transmitted. The pin-point indentations produced on the specimen by the set screws permitted length "L" to be accurately picked off the specimen with draftmen's dividers.

The alignment jig shown in Figure III was used to insure that the face of the indicator-arm collar, hence the plane of the set screws, was perpendicular to the axis of the specimen.

The lower half of the specimen rests on a machined and polished steel plate. For initial tests on the steel specimens a machined steel block was used, as shown in Figure I (1). The remainder of the specimens were mounted on the machined steel block shown in Figure III. This block has a securing collar which permits clamping of the bottom end of the specimen. After a final cleaning of the two contact surfaces, the upper half of the specimen was placed on the lower portion, and the weight rod then run up through the annulus of the specimen. The weight release (screw jack) permits the weight pan support rod to be run up and down as desired.

Belgian women: foreign women are not a threat

[illegible]

The alignment of the shaft in Figure 11 was used to locate the top of the indicator collar, since the shaft of the indicator was perpendicular to the axis of the shaft.

The lower half of the specimen consists of a well-defined and polished steel plate. The upper half of the specimen is a well-defined steel plate, as shown in Figure 1 (a). The thickness of the specimen was measured on the polished steel plate shown in Figure 1 (b). This figure has a circular hole which permits clamping of the specimen and of the specimen.

After a final viewing of the two original negatives, the upper half of the specimen was placed on the lower portion, and the weight was then put up through the opening of the specimen. The weight released (about 1000) provided the weight was removed and the two were as desired.

The threaded upper end of the rod was then screwed into a circular disc, separated from the top of the specimen by a ball thrust bearing as illustrated in Figure III. This bearing was used to isolate the specimen from any torsional vibration or movement of the normal load weight pan.

The sight edges are pictured in Figure I (2) and Figure III. The two sight edges were polished with 4/0 paper so that a clean, sharp sighting surface was obtained. Alignment of the two sight edges could be obtained by loosening either one or both of the clamp screws, and moving the edges into position as desired. The upper arm sight edge strip was out wider than that on the lower arm. The distance from this edge to the center of the indicator-arm collar was measured accurately (12.33"), giving length "R". With the microscope focused sharply on this edge, the other sight edge strip was brought into focus by bending it slightly.

The torque arm was aligned so that the silk threads transmitting the forces from the torque weight pans are perpendicular to the lever in both horizontal and vertical planes. The pulleys were adjusted in both vertical and horizontal planes by moving pulley clamps on the support rods, as shown in Figure II. When alignment of the torque system was obtained, the torque arm and pulley support clamps were locked in place with their set screws.

The desired normal load was placed on the weight pan and then applied to the specimen by cranking down the weight release.

The zero reading of the indicator arms was then recorded.

The affected joint and of the two were removed from
a separate area, containing from the top of the specimen of a
well known bedding is illustrated in Figure 11. This bed-
ding was used to illustrate the specimen from the specimen of the
kind of movement of the normal bed which was
The slight change in position is shown in Figure 12 and
Figure 13. The two slight changes were indicated with 40 and 45
on the right, showing slightly further up the bed. The
most of the two slight changes would be indicated by increasing
either one or both of the slight changes, and noting the change
into position as indicated. The upper and lower edges were
not shown that on the lower side. The distance from this
edge to the center of the indicator was called out separately
separately (12.75) is divided into 40. The distance
between slightly on this side, the other edge was also
measured from the center to the edge of the bed.
The bottom edge was aligned so that the two edges
were parallel to the center from the lower edge and the
measured to the lower in both horizontal and vertical planes.
The edges were aligned in both vertical and horizontal
planes in moving along along on the vertical side. As shown
in Figure 11. When alignment of the bottom edge was obtained,
the bottom edge was aligned along with the lower edge
with the two edges.
The bottom edge was placed on the right side and
then moved to the position by moving down the right side.
The two edges of the indicator were not then removed.

By adding equal weights to the two weight pans, a known torque was applied to the specimen and the resulting twist was measured on the optical micrometer. After each reading the torque was removed and the zero reading recorded.

After measuring the distance "L" between pin-point indentations in the specimen, these pits were marked so that they could be distinguished from marks made in the succeeding test.

by taking special permits to the few nights each, a known person
was assigned to the position and the necessary permit was obtained
from the local authorities. They were then taken to the
place and the necessary permit was obtained.

After consulting the Director of the Bureau of the Census, it was determined that the Bureau is the proper agency to handle this matter and that the Bureau should be contacted for further information.

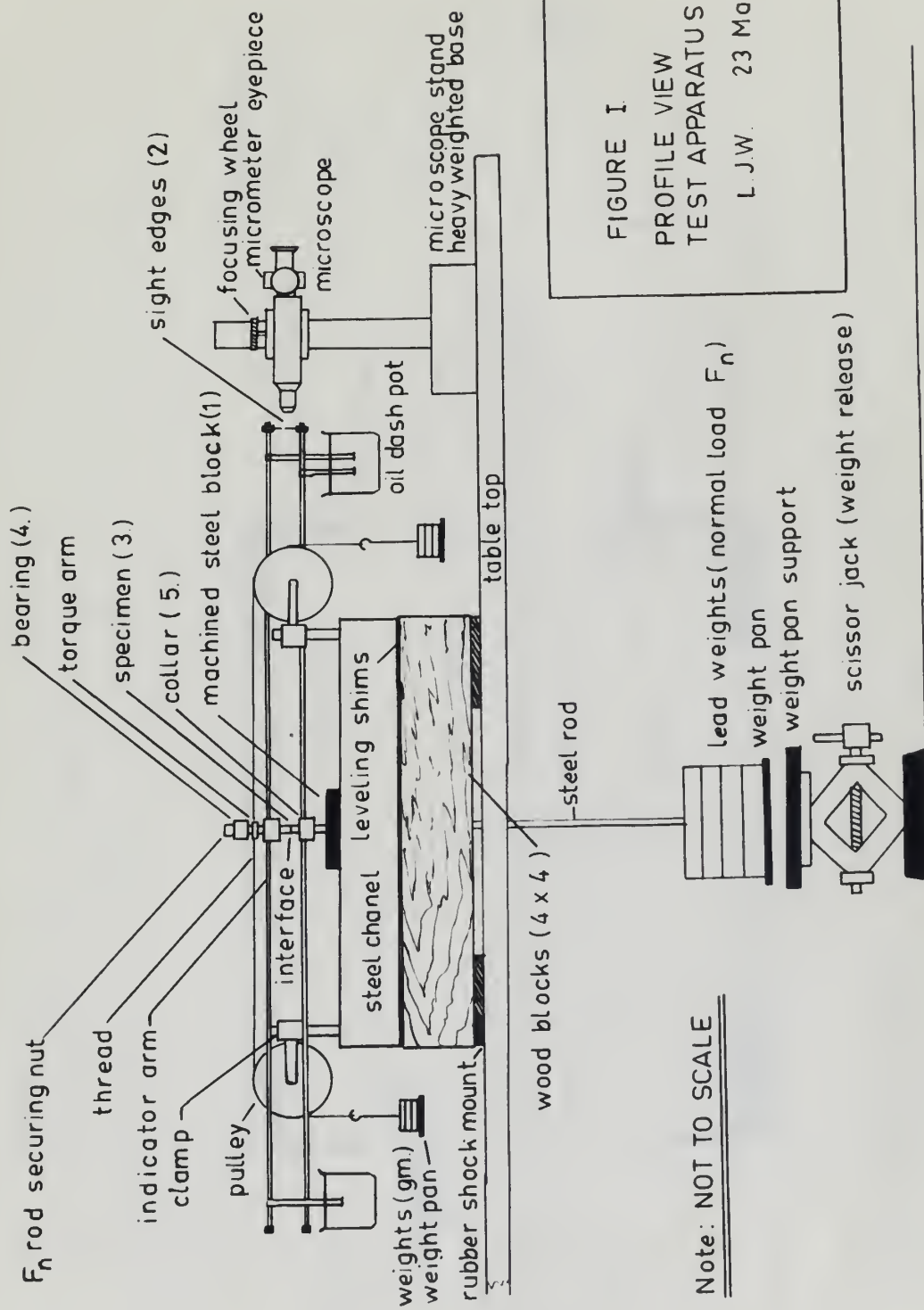
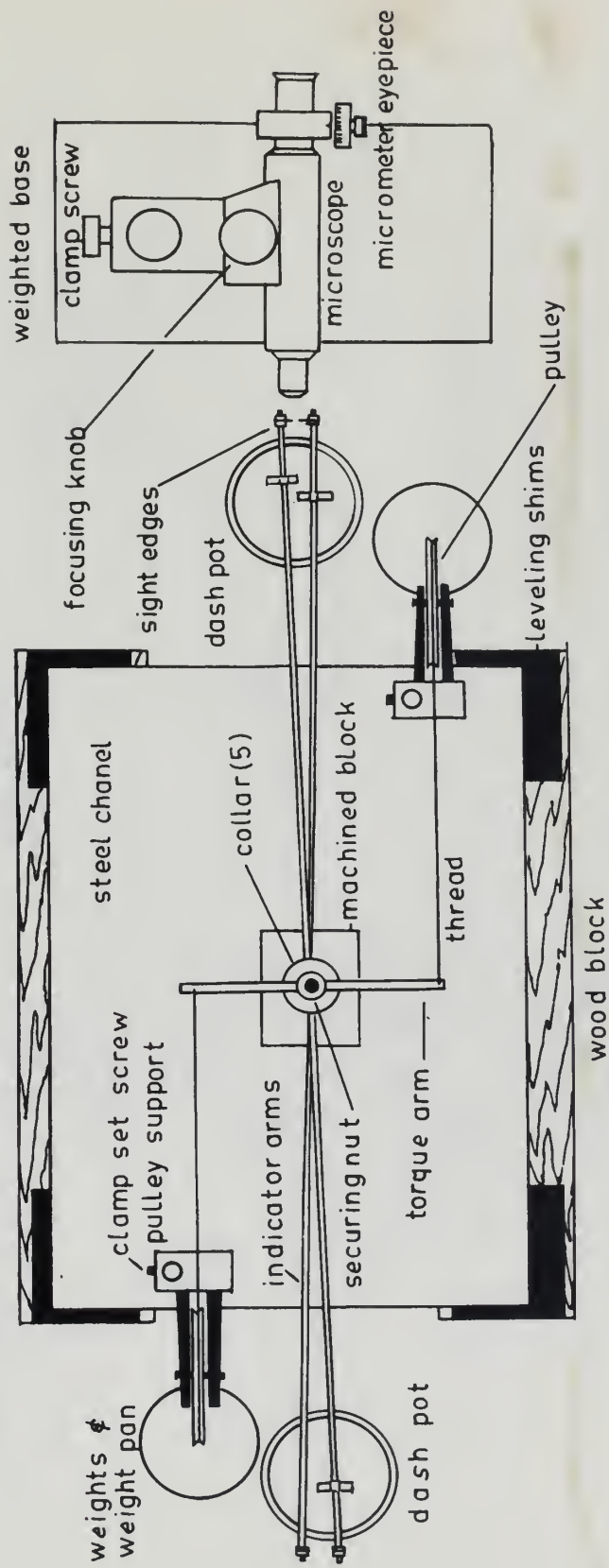


FIGURE II.
PLAN VIEW OF TEST APPARATUS



Note: NOT TO SCALE

L.J.W. 23 May, 1955

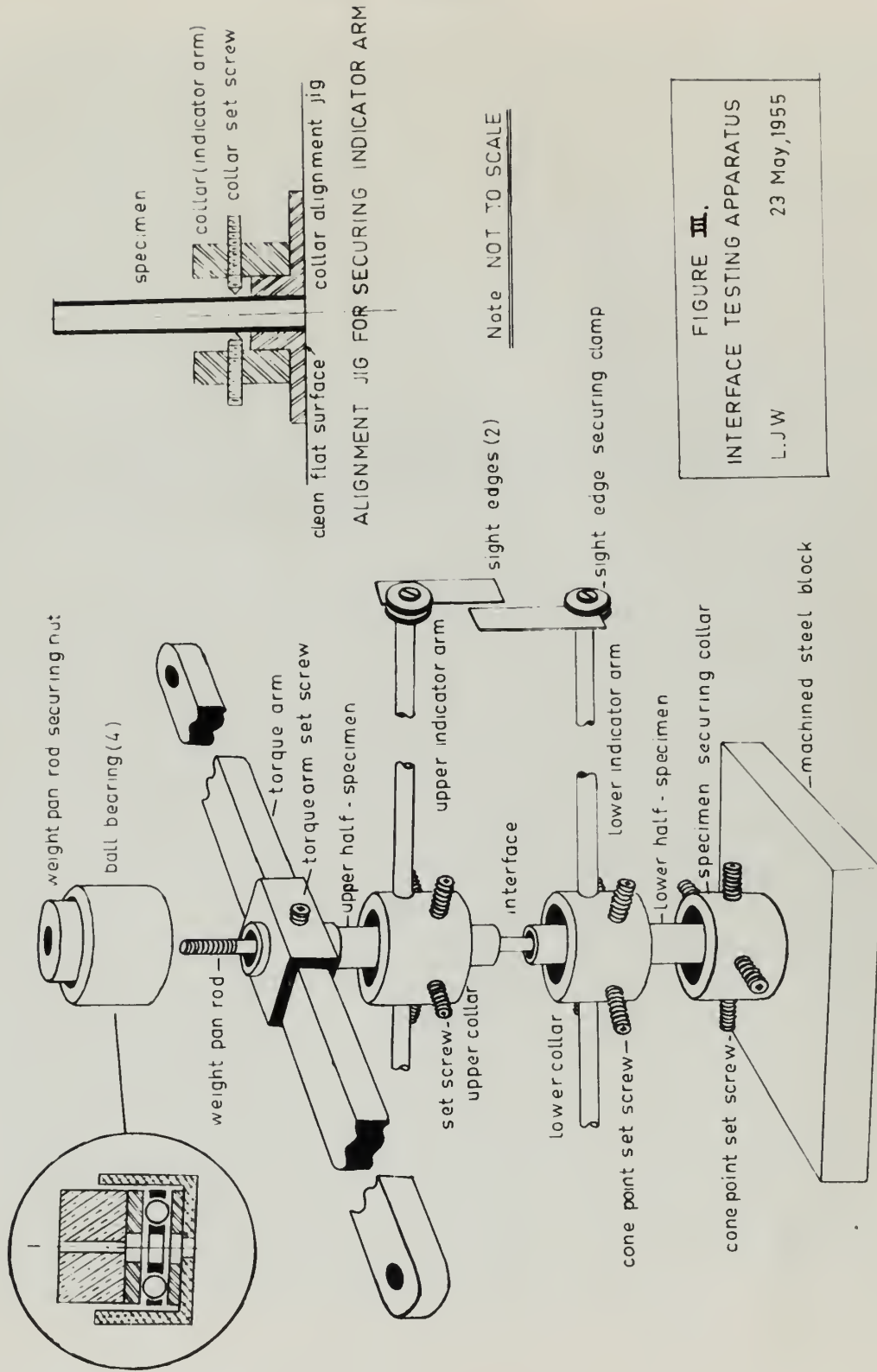


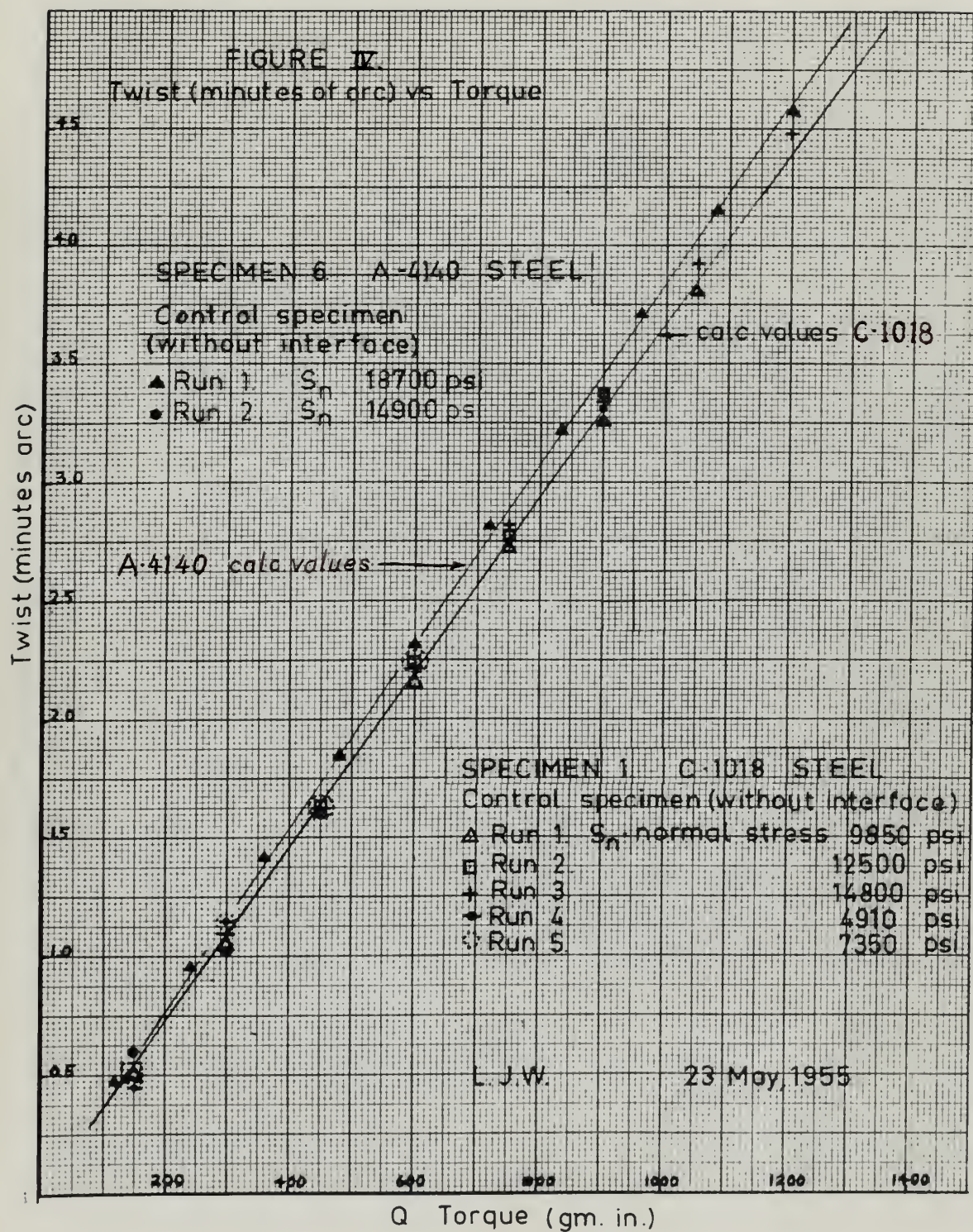
FIGURE III.
INTERFACE TESTING APPARATUS

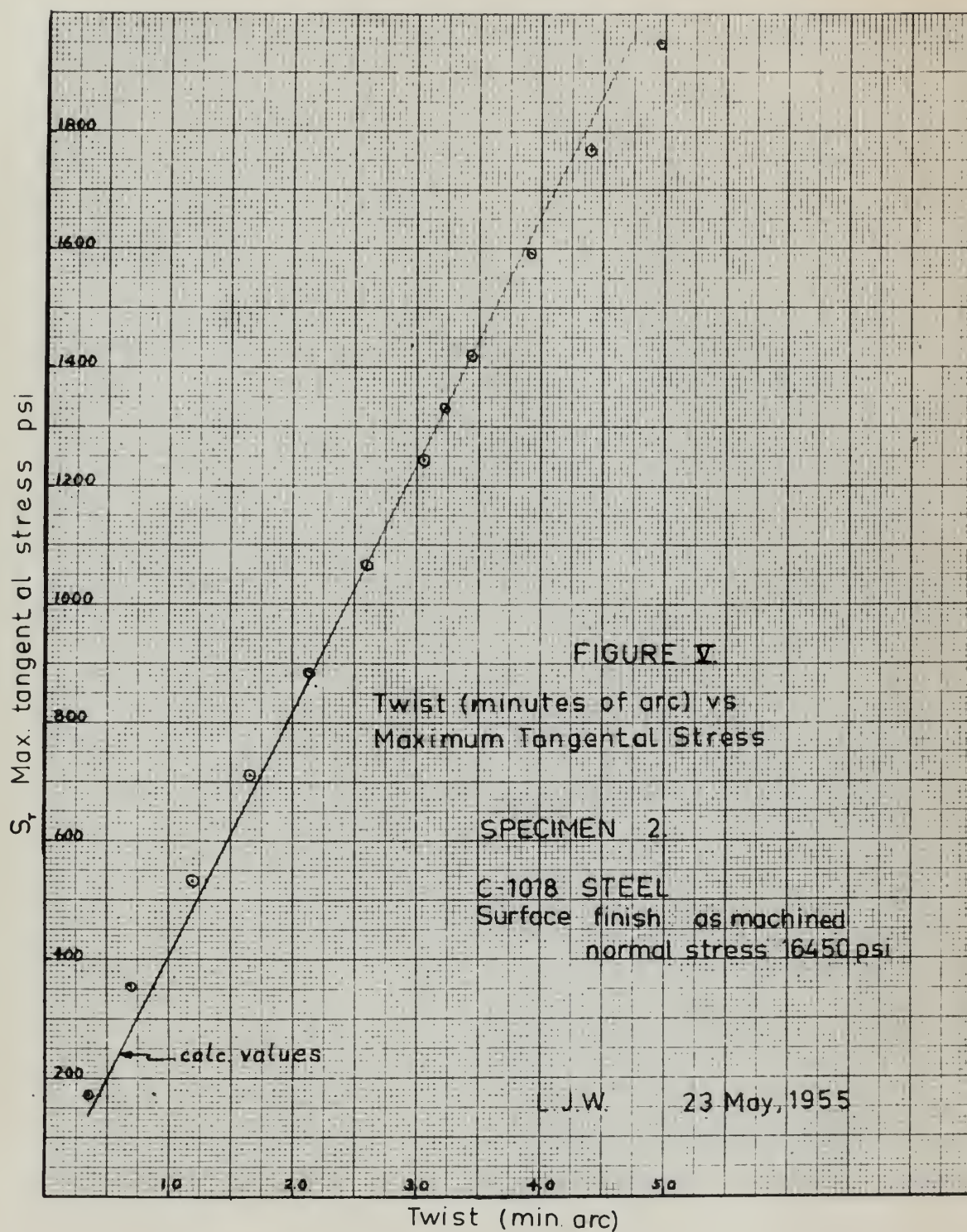
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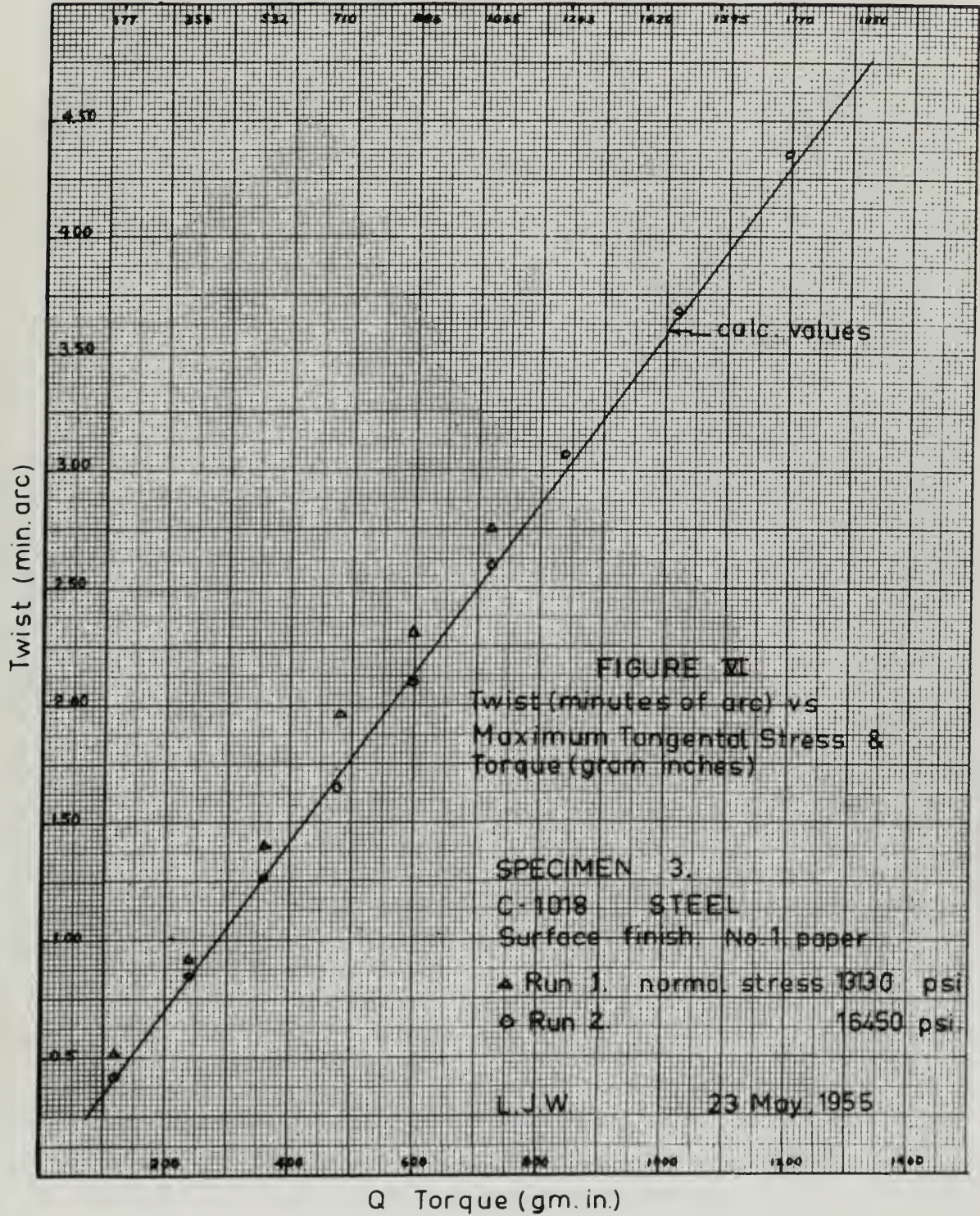
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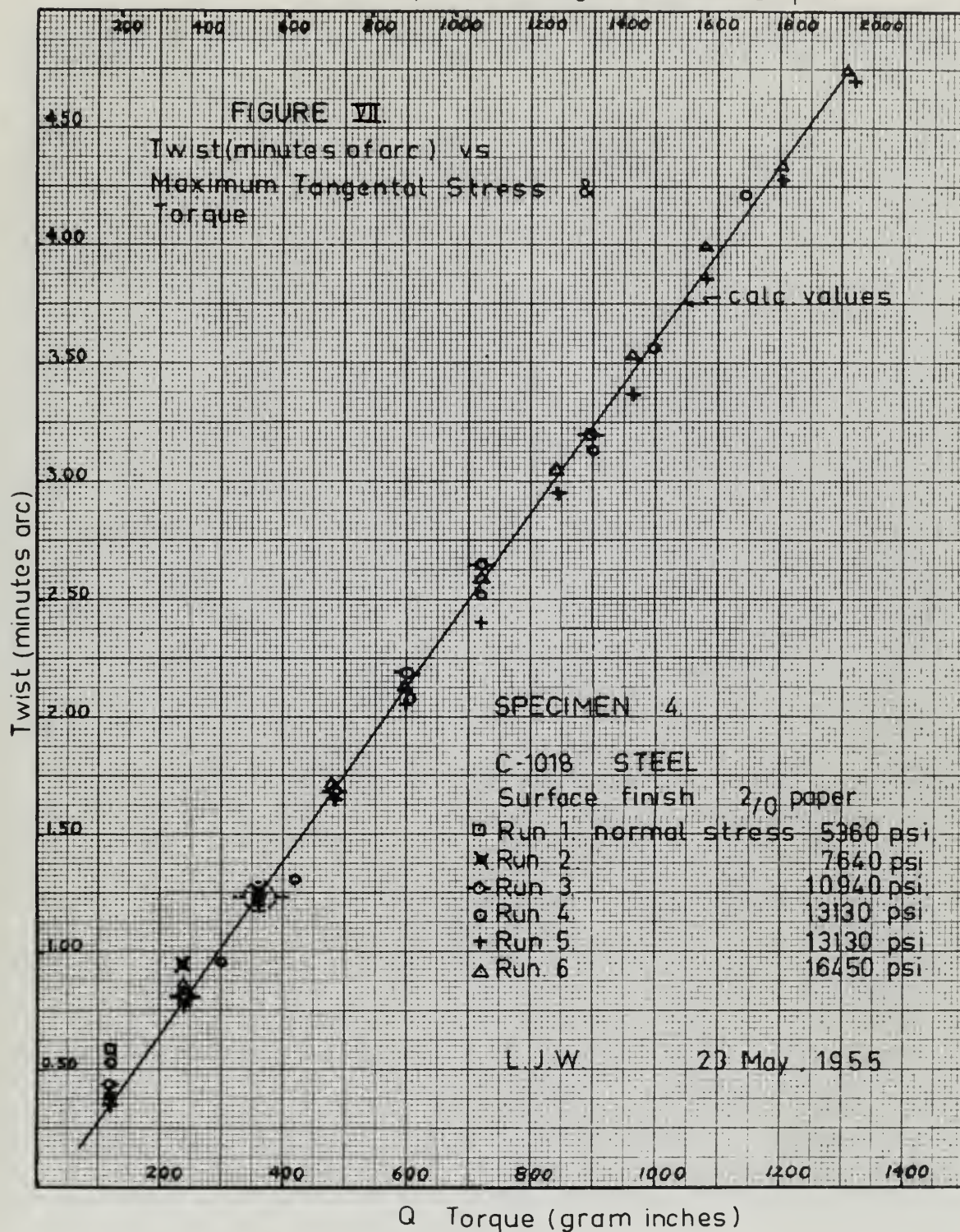
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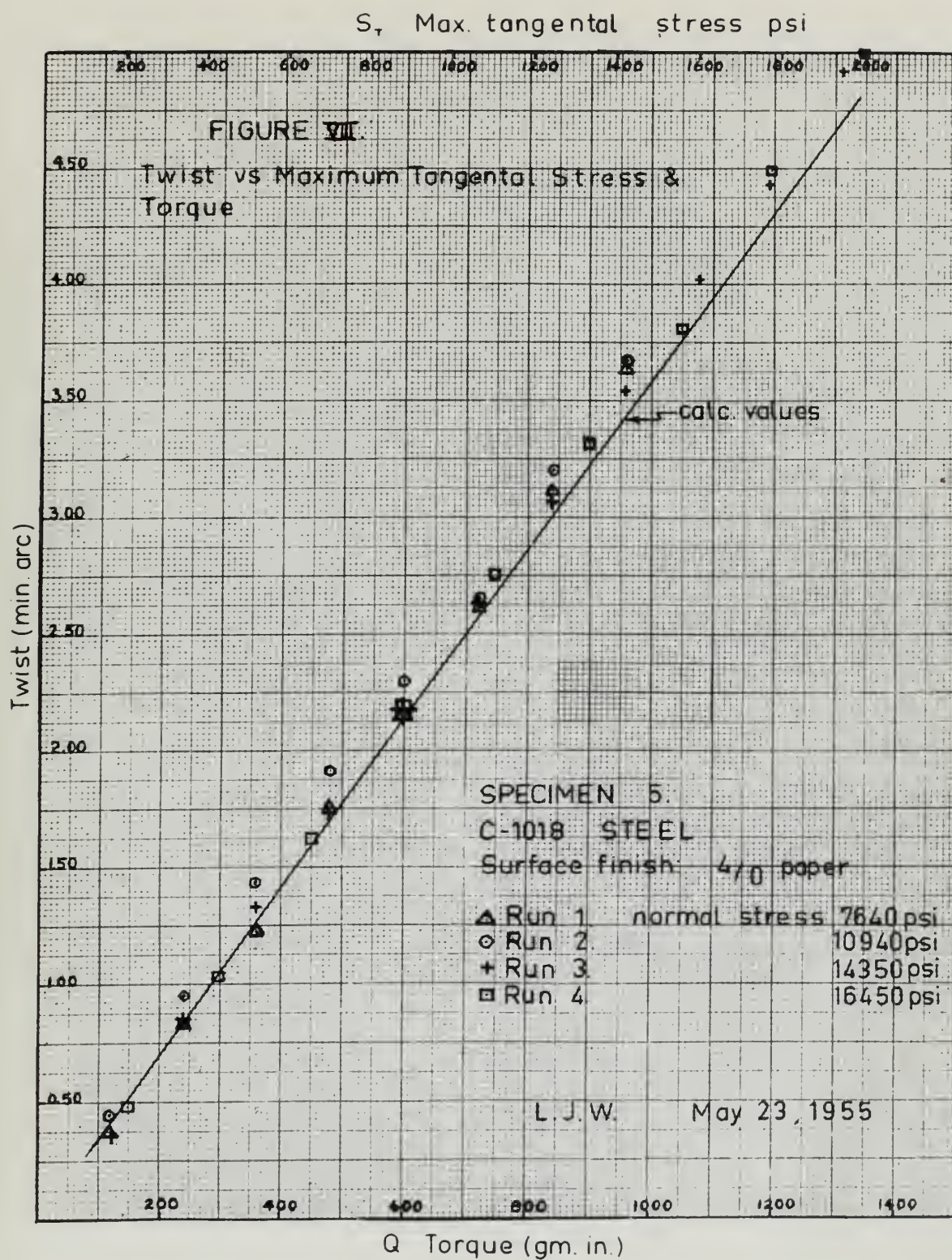
The results of this investigation are shown in
 Figures IV to VII, inclusive.





$S_T = \text{Max. tangential stress psi}$


S_r = Max. tangential stress psi




S_r = Max. tangential stress psi

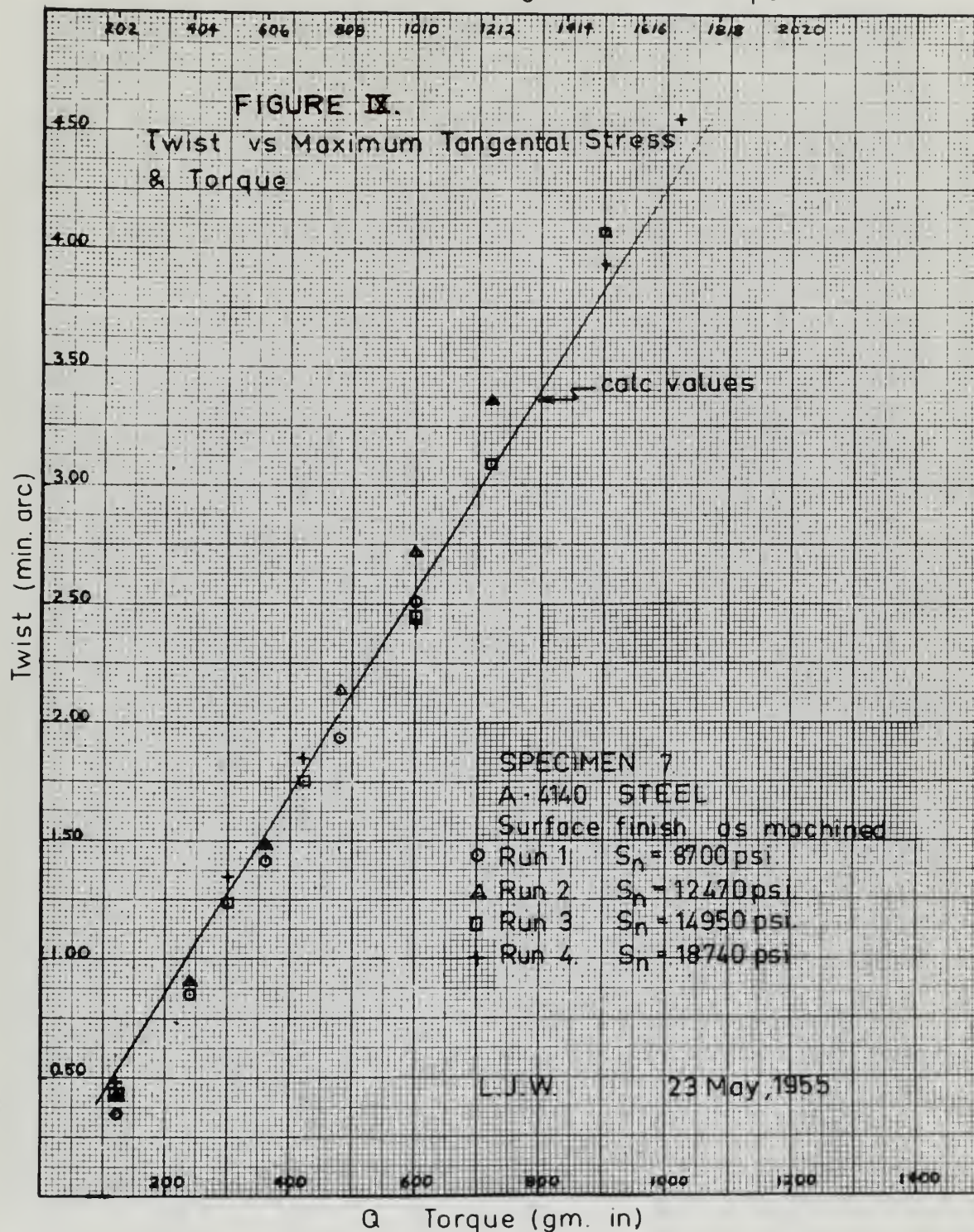


FIGURE X.
TWIST VS MAXIMUM TANGENTIAL STRESS

SPECIMEN 13.

Copper surface finish #1 paper

Run 1 $S_n = 11170$ psi

Run 2. 13360 psi

Run 3. 16700 psi

calc. values Copper

calc. values A-4140

SPECIMEN 8.

A-4140 steel surface finish #1. paper

Run 1. $S_n = 8700$ psi

Run 2. 12470 psi

Run 3. 14950 psi

Run 4. 18740 psi

L.J.W. May 1955

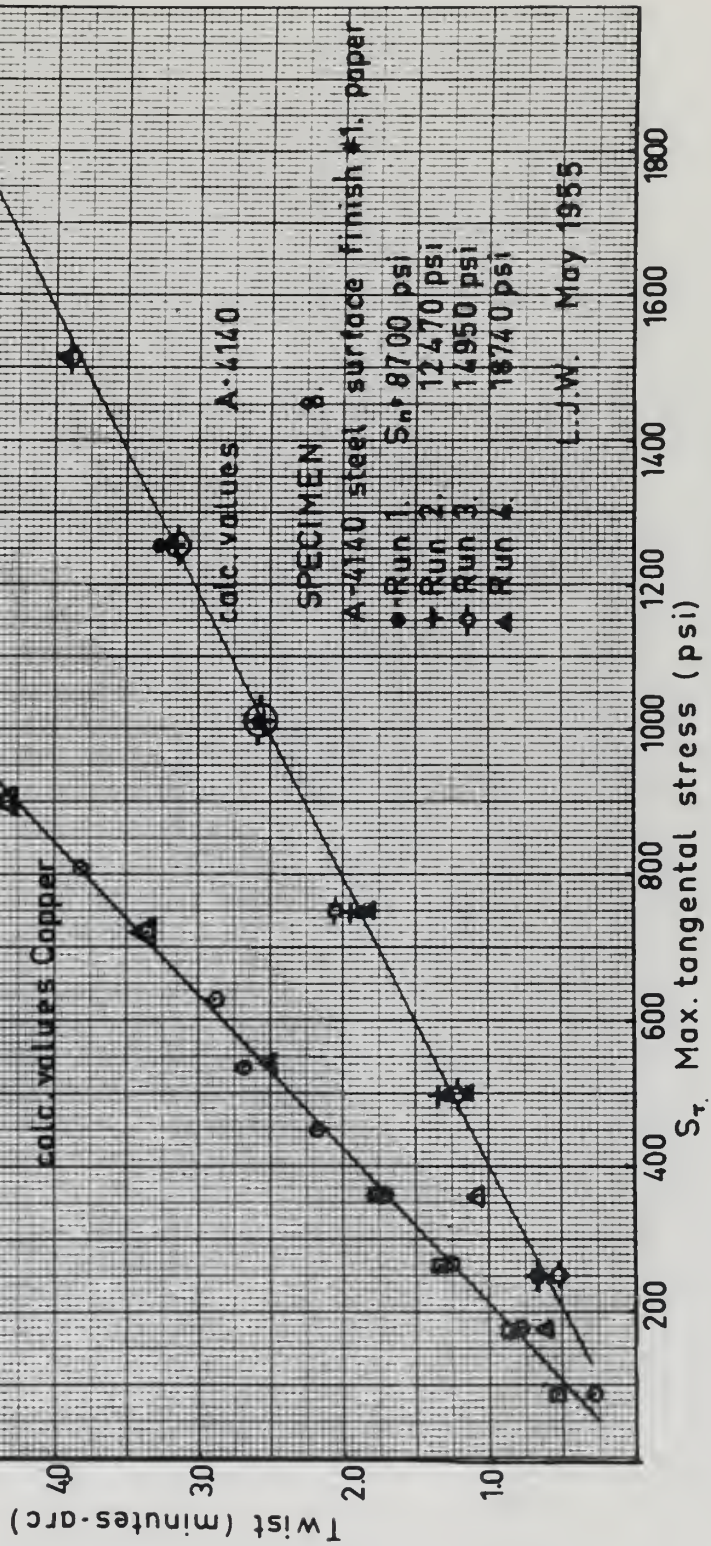


FIGURE XI.

TWIST vs MAXIMUM TANGENTIAL STRESS

SPECIMEN 14.

Copper surface finish 2/0

- ◇ Run 1 $S_n = 4300$ psi
- △ Run 2. 7800 psi
- + Run 3. 11170 psi
- Run 4. 13360 psi
- Run 5. 15400 psi

calc. values copper

calc. values A-4140

SPECIMEN 9.

A-4140 steel surface finish 2/0

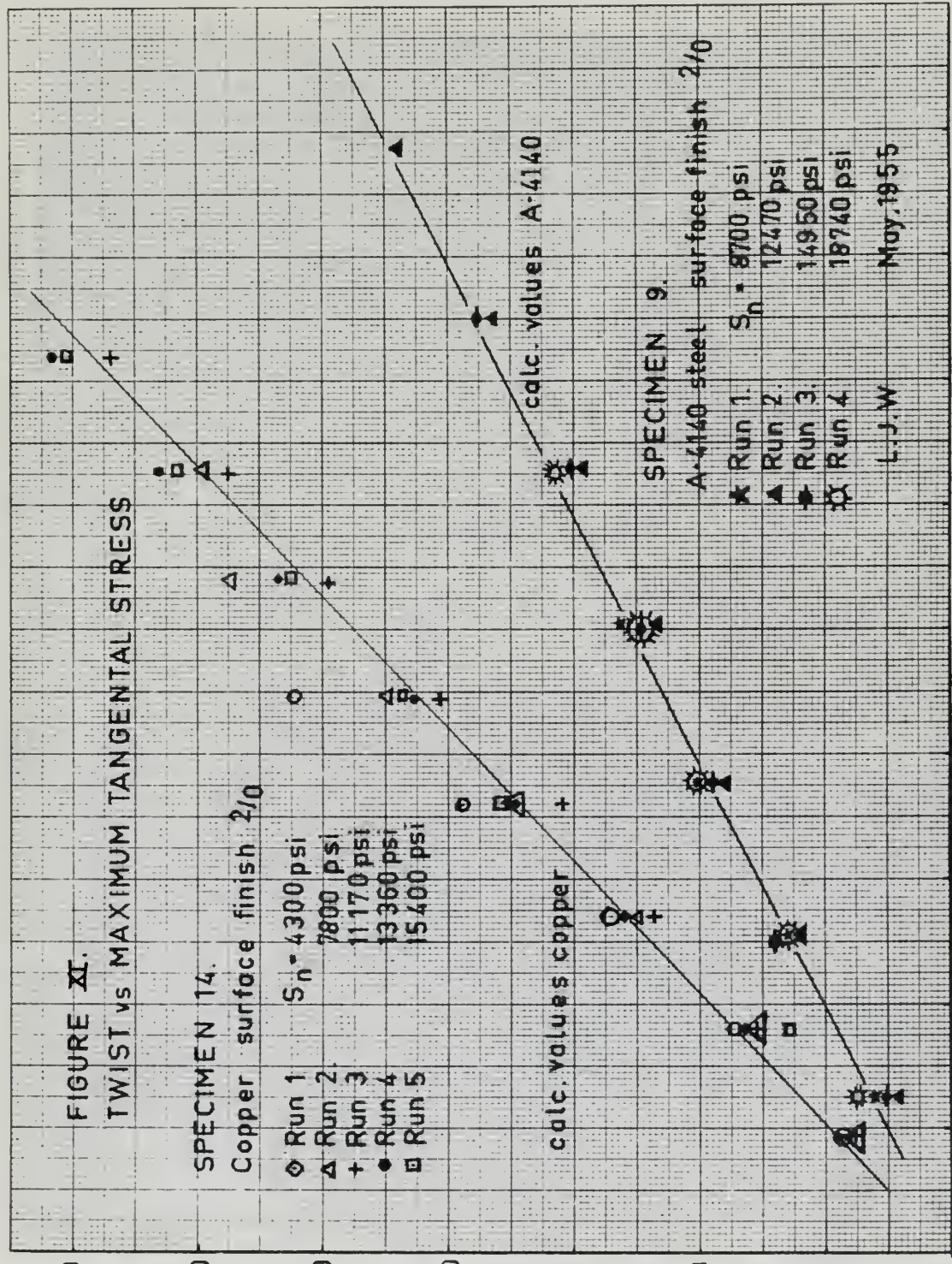
- ★ Run 1. $S_n = 8700$ psi
- △ Run 2. 12470 psi
- Run 3. 14950 psi
- ⊗ Run 4. 18740 psi

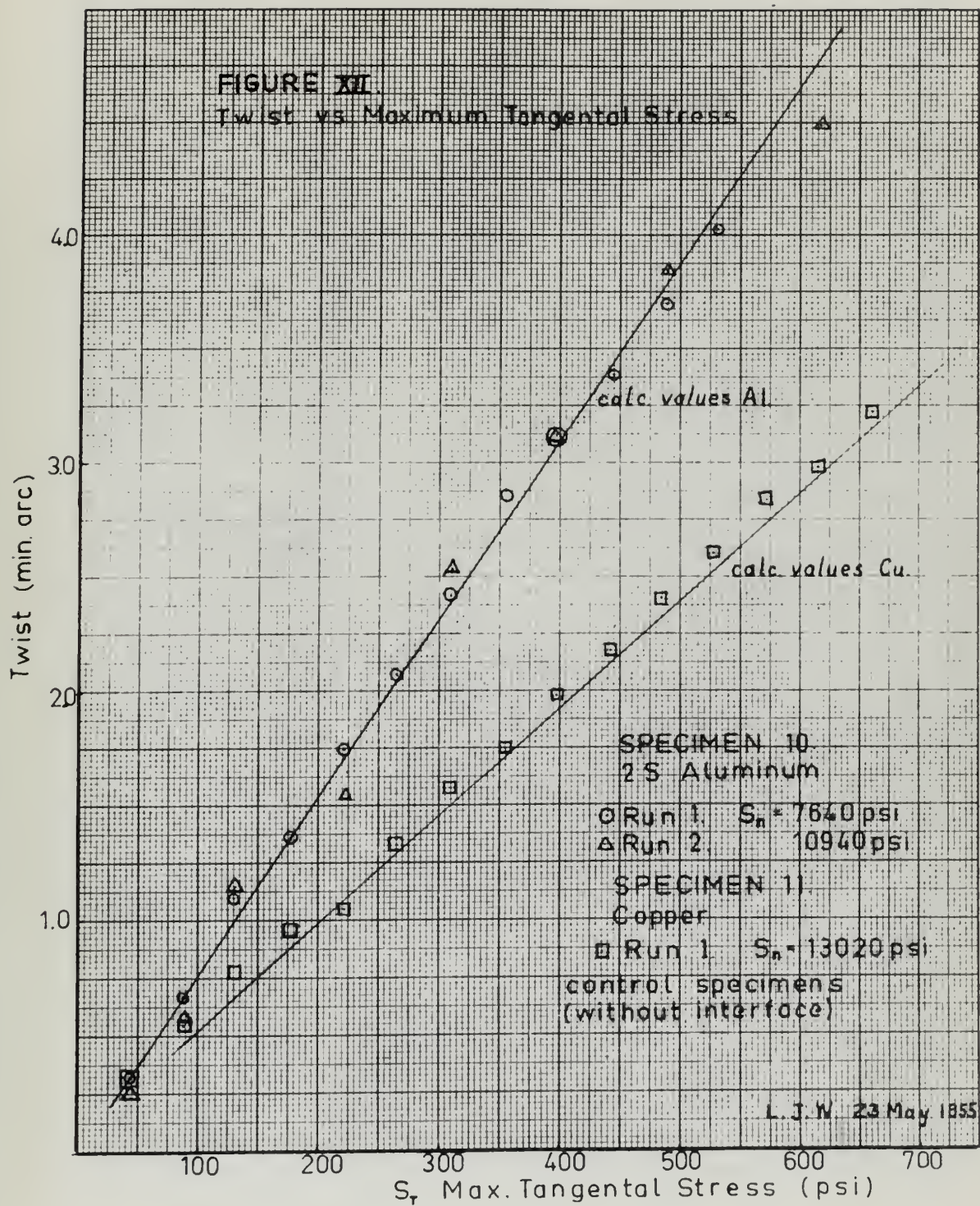
L.J.W

May. 1955

Twist (minutes-arc)

S_t Max. Tangential Stress (psi)





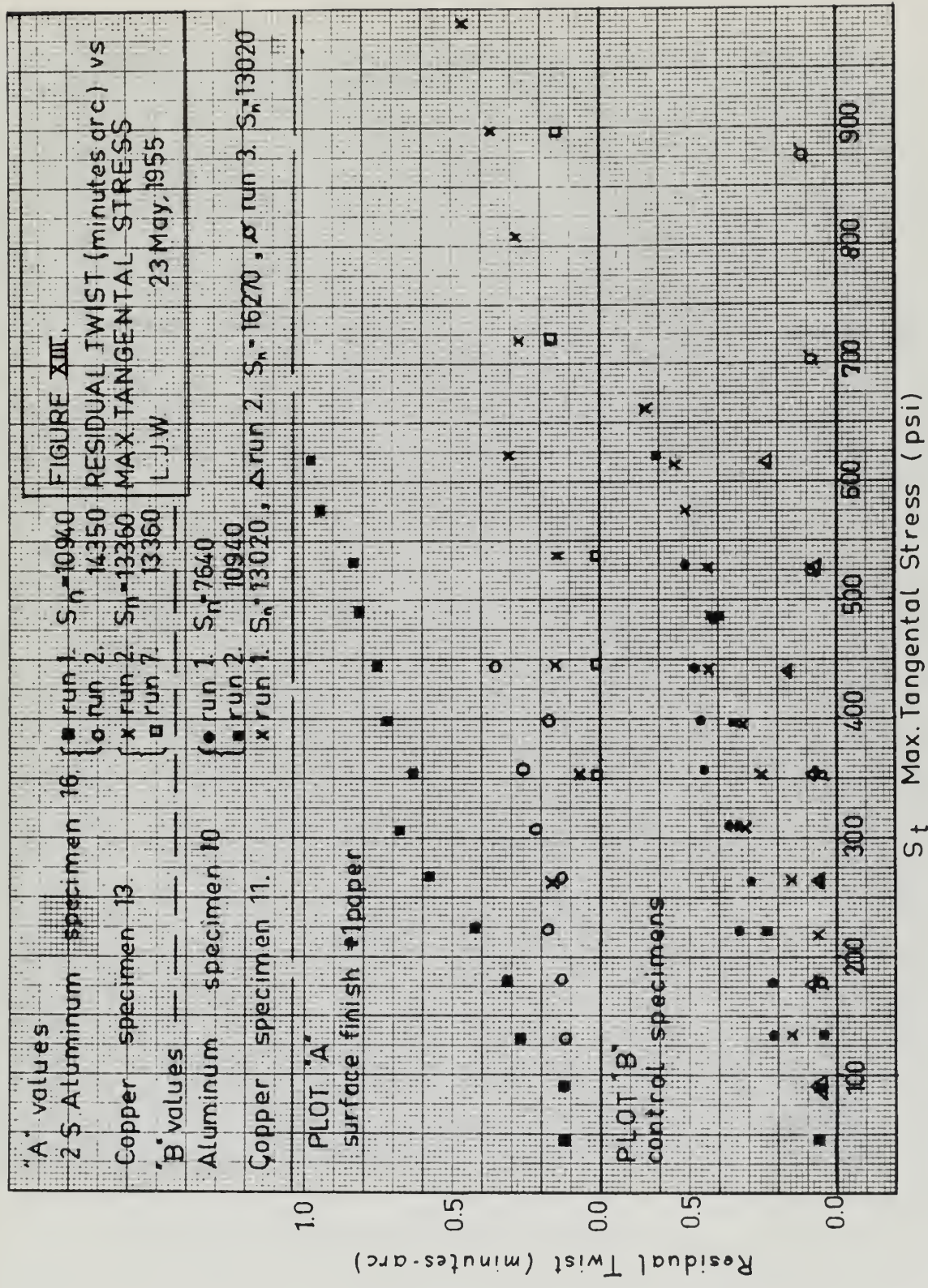


FIGURE XIV

Maximum Tangential Stress vs
Apparent Slip at Interface

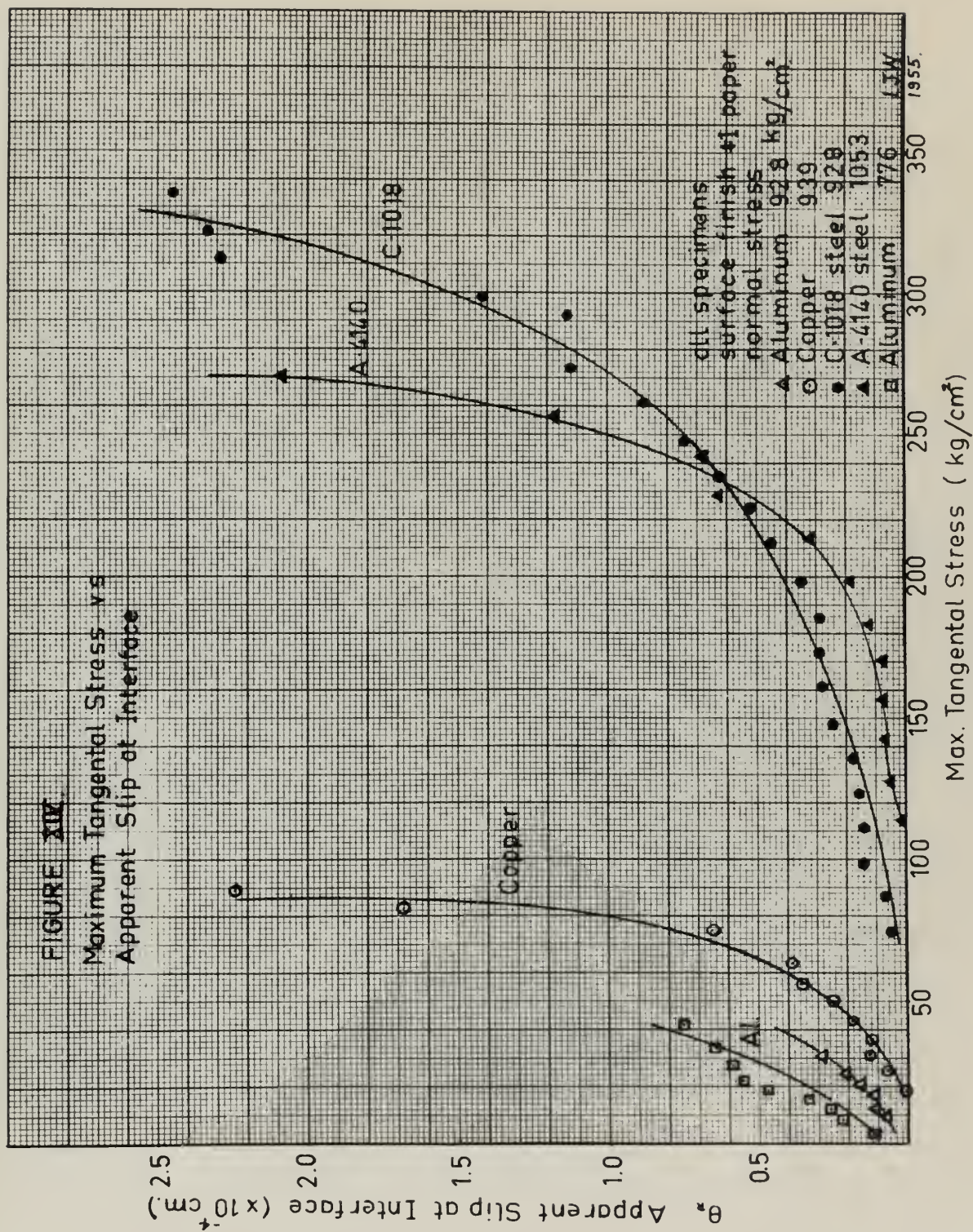
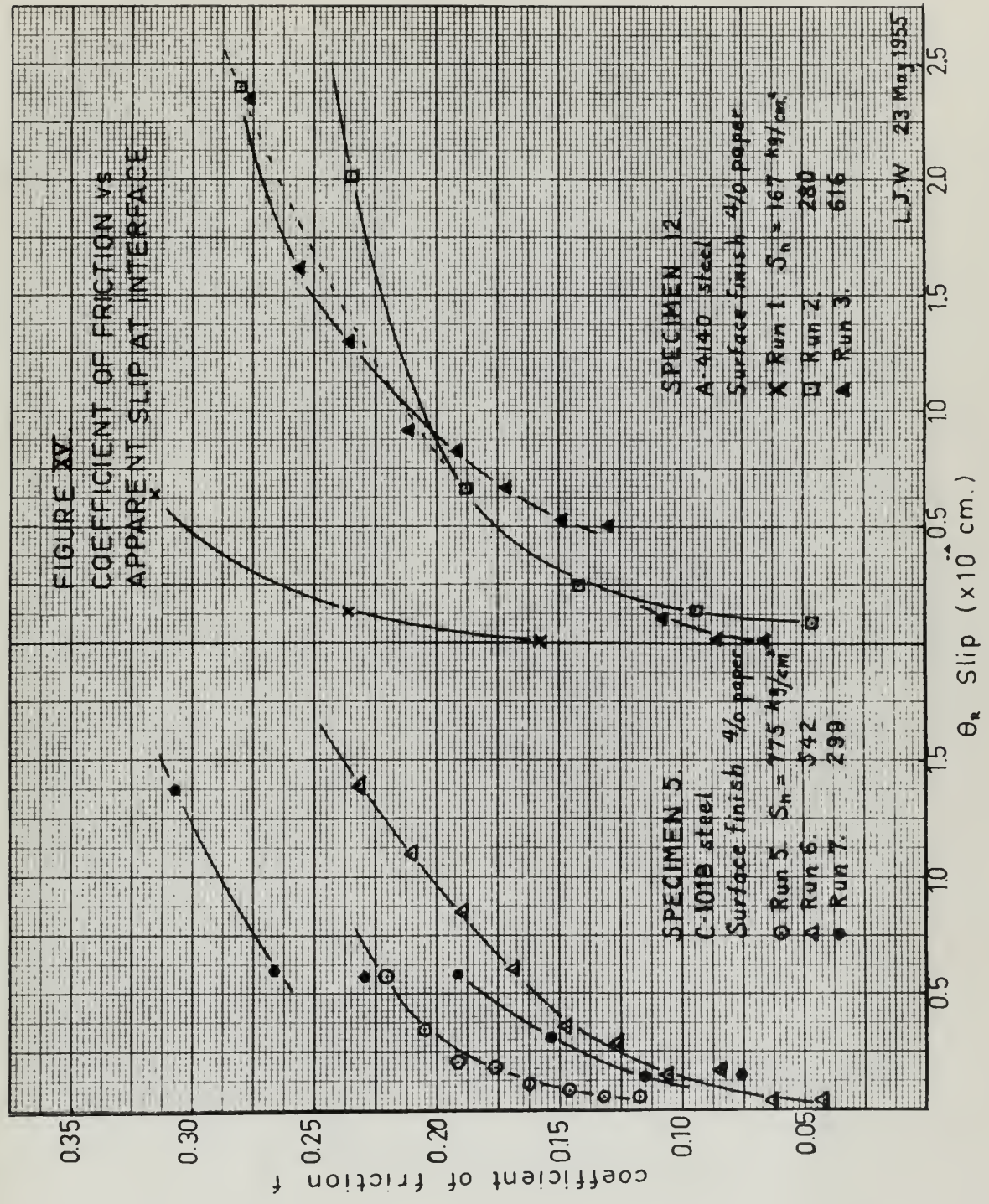


FIGURE XV.

COEFFICIENT OF FRICTION VS
APPARENT SLIP AT INTERFACE



LJW 23 May 1955

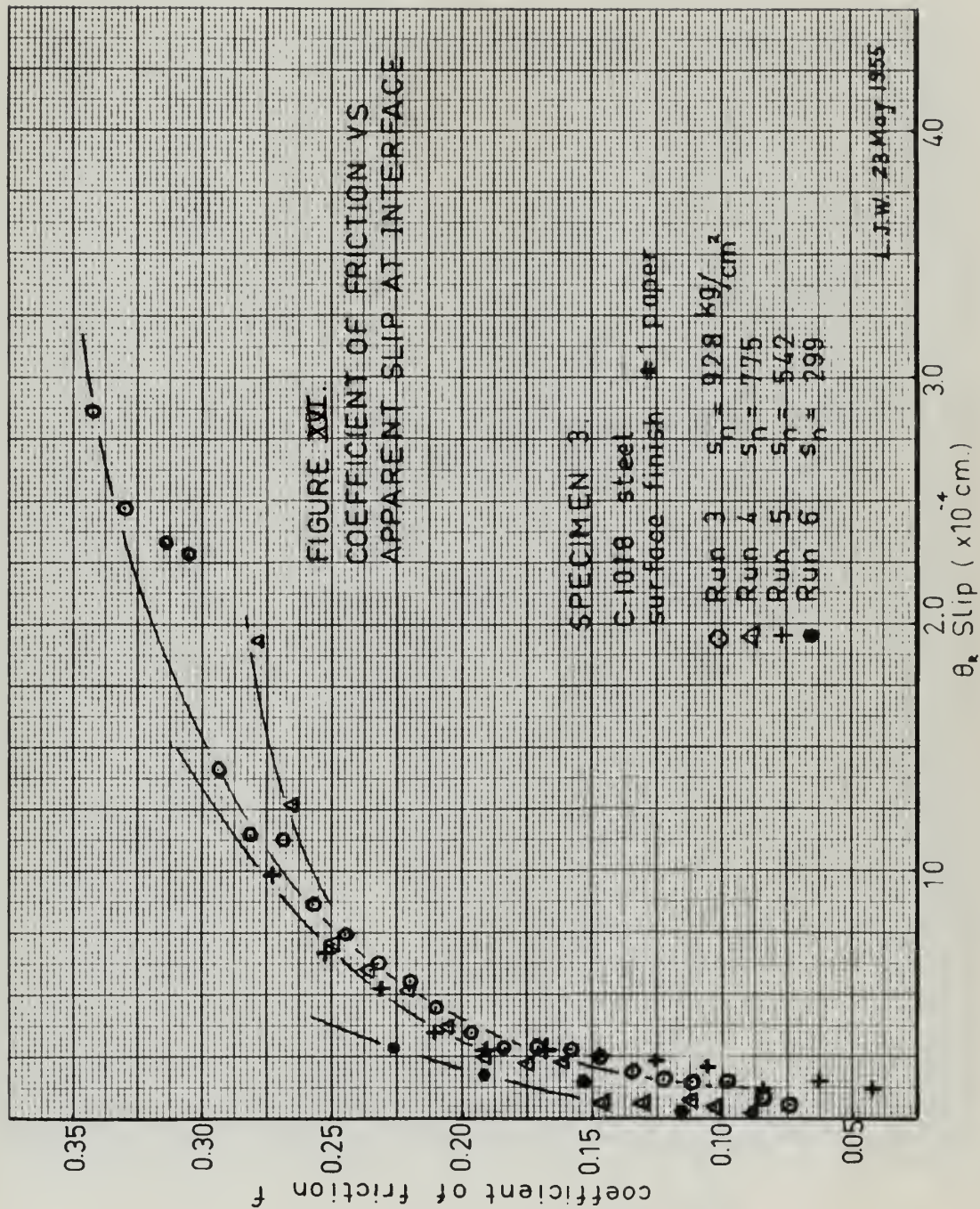


FIGURE XVII.

Coefficient of Friction vs.
Apparent Slip at Interface

0.3

coefficient of friction f

0.2

0.1

1.0

2.0

3.0

4.0

 θ_R Slip ($\times 10^4$ cm.)

SPECIMEN 8

A 4140 surface finish #1 paper

● Run 7 $S_n = 1053$ kg/cm²▲ Run 8 $S_n = 883$ ○ Run 9 $S_n = 616$ + Run 10 $S_n = 340$

L.J.W. 23 May 1955

 $f = 0.155$ at 0.30×10^4 cm.

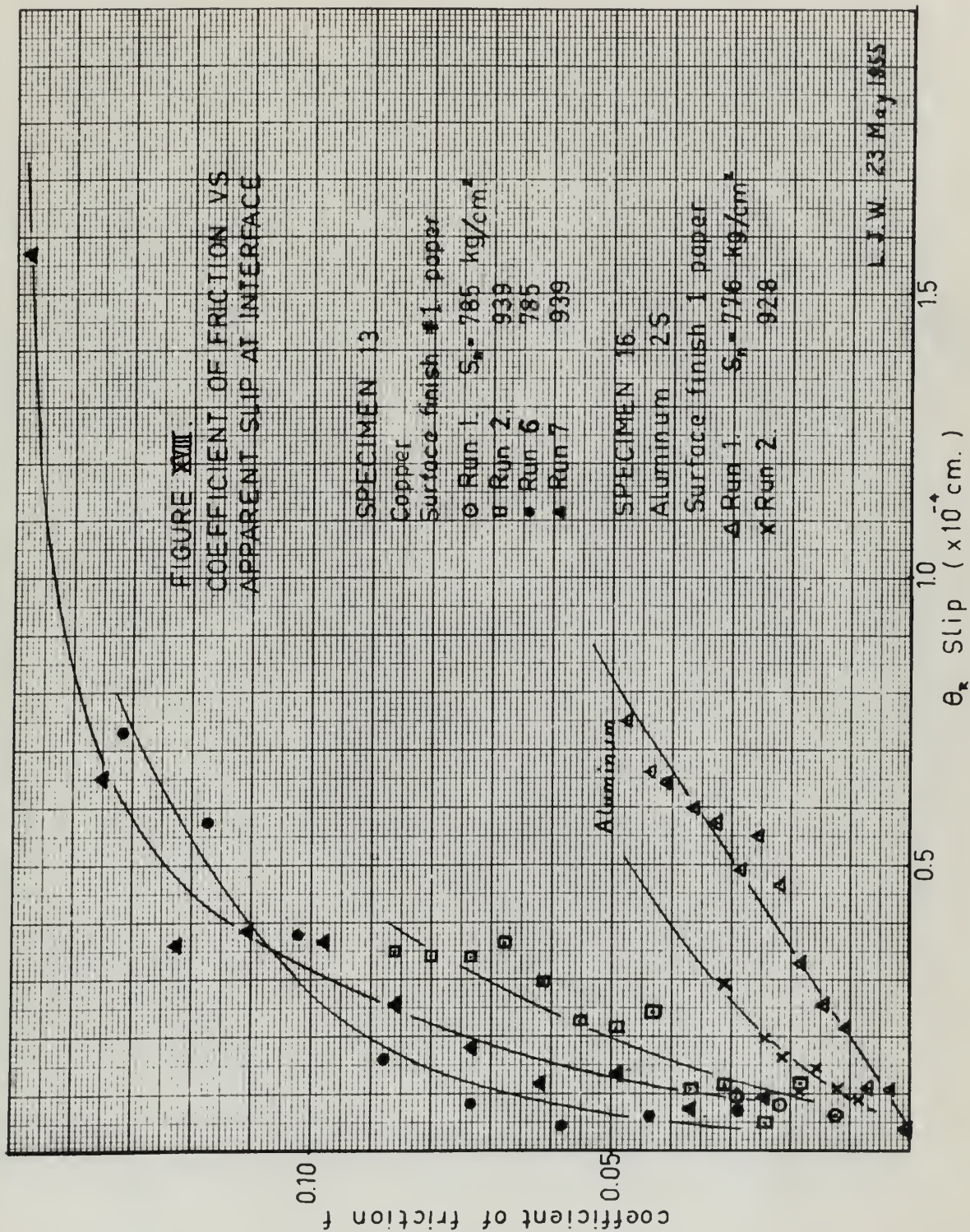
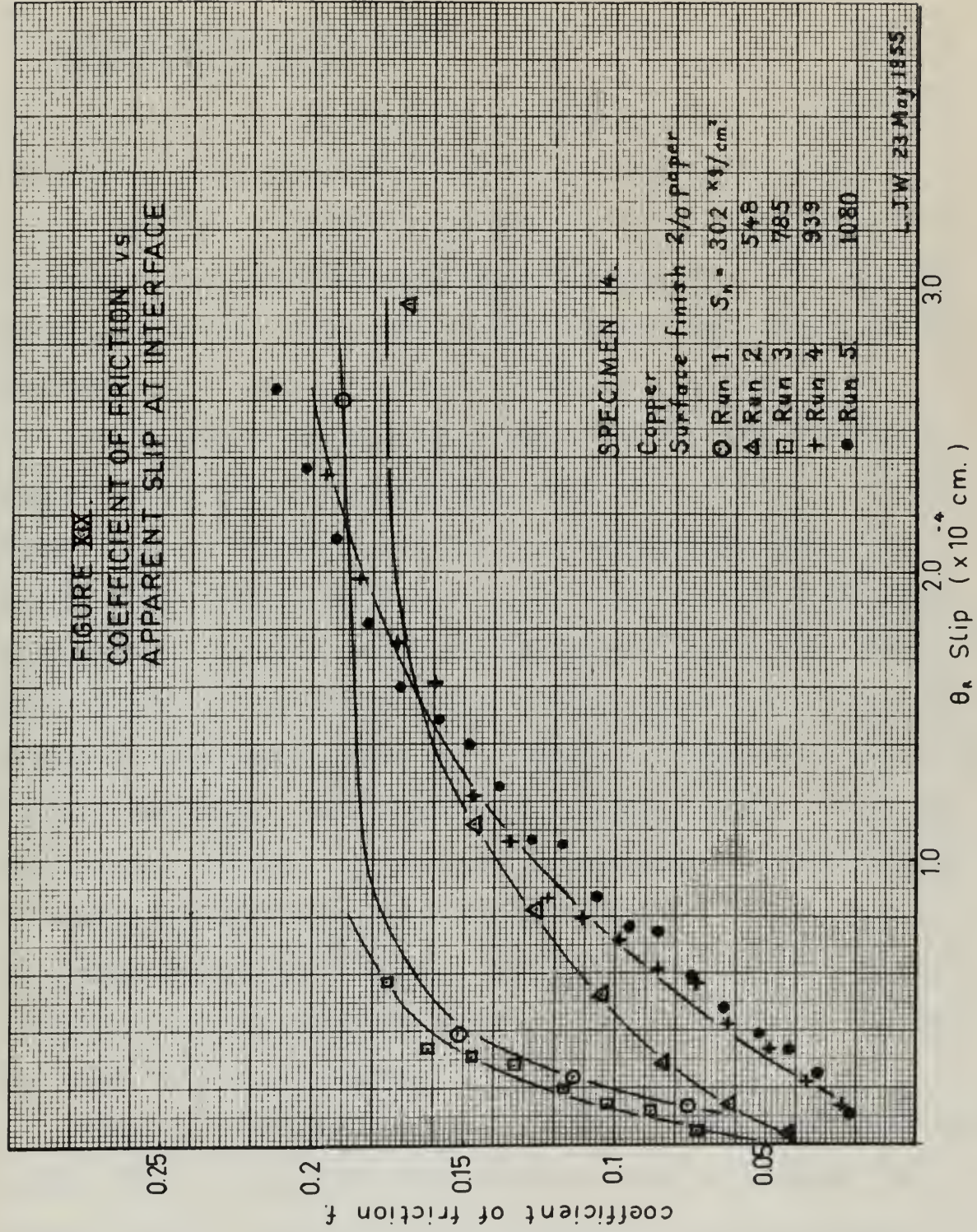


FIGURE XXX.
COEFFICIENT OF FRICTION vs
APPARENT SLIP AT INTERFACE



IV. DISCUSSION OF RESULTS

A. Initial Elastic Behavior of Metal Interfaces

Figures IV and XII compare observed deflections of the control specimens with computed deflections as predicted by elastic theory. All points plotted for the two steel control specimens are within the elastic range, as the test runs were terminated at the first indication of possible permanent deformation.

The values of shear modulus selected for the C-1018 and A-4140 steels were, respectively, 12×10^6 and 11.9×10^6 psi. Marks⁽⁶⁾ gives the range of shear modulus values for all steels, excepting 18-8 stainless, as 11.0 to 11.9×10^6 psi. The computed angle of twist varies inversely with the value of shear modulus. Therefore it can be seen that, with the values of shear modulus selected, the computed deflections will be the minimum expected. As the observed values of twist agree with the minimum computed values, the possibility of excessive elastic twist in the control specimen is eliminated.

The shear modulus values for copper (hard-drawn tough pitch) and 28 Aluminum were given in the Handbook as 6.0 and 3.7×10^6 psi, respectively.

Figures V to VIII show the results of tests conducted with C-1018 steel specimens having various surface finishes and normal loads. Due to the close agreement between observed and

1. Initial Elastic Properties
of Metals, 1947, p. 104

Figure 10 shows the observed behavior of the control specimen with respect to the initial elastic properties. All points plotted for the two steel samples are within the limits of the initial range, as the test was terminated at the first indication of possible permanent deformation.

The values of initial modulus obtained for the 4130 and 5140 steels were, respectively, 1.8×10^6 and 1.7×10^6 psi. ^(b) gives the range of initial modulus values for all steels, respectively 1.8×10^6 to 1.7×10^6 psi. The observed range of initial modulus values for the steel samples is shown in Figure 10. It can be seen that, with the values of initial modulus obtained, the observed behavior will be in the initial elastic range. As the observed values of initial modulus are within the range of the initial elastic range, the possibility of permanent deformation in the control specimen is eliminated.

The initial modulus values for copper (hard-tempered) and 5140 steel were given in the Appendix as 1.7×10^6 and 1.7×10^6 psi, respectively.

Figure 7 to 10 show the results of tests conducted with 5140 steel specimens having various initial moduli. As the initial modulus values are within the range of the initial elastic range, the possibility of permanent deformation in the control specimen is eliminated.

computed values of deflection for the control specimens, the observed angles of twist are compared with their corresponding theoretical value in this work.

The consistent agreement between test results for specimens with and without interfaces indicates that the interface has very little, if any, effect on the elastic twist.

All test runs with non-ferrous specimens were performed with the lower end of the specimen locked against movement. These test runs extended past the point at which the indicator failed to return to the initial position. The "B" plot of Figure XIII gives the observed values of residual twist recorded for the non-ferrous control specimen runs shown on Figure XII. Hard-drawn electrolytic tough pitch copper has a yield strength of 40,000 psi with 0.5% extension under load. Three successive runs on the copper control specimen show this effect clearly. The recorded values of deformation decreased with each run. Plot "A" of this figure shows the residual twist recorded for similar runs conducted on specimens with a No.1 surface finish. The effects contributed by the metal interface can easily be obtained by subtraction of the plotted values for any two corresponding tests. The point at which slip occurs on the copper specimen is easily noted, as the residual twist value increased sharply at that point.

Figures X and XI compare observed and calculated values of deflection for various test runs on copper and A-4140 steel specimens. These tests further substantiate the results recorded previously for C-1018 steel. Test runs using copper,

[illegible]

C-1018 steel, or A-4140 steel under various conditions of normal loading and with different degrees of surface finish failed to indicate any material contribution by the interface to elastic twist.

B. Initial Frictional Behavior of Metal Interfaces

Figure XIV compares the results of a similar test run conducted on four different metals. Comparing the results of the two steel specimens, it is seen that deformation occurred first in the C-1018 steel. This is attributed to yield in the asperities in the metal interface. C-1018 steel, with a yield strength of 48,000 psi as compared with 131,000 psi for the A-4140, would be expected to yield first. It should be noted that the deformation observed here is of the order of 0.000005 cm. The C-1018 curve crosses the A-4140 line at an apparent slip value of 0.00006 cm. This shows that sliding effects are now predominant, as the A-4140 steel with its smaller coefficient of friction slides more easily than the C-1018 steel.

Deformation in the two non-ferrous specimens commenced at fairly low values of tangential stress. It is interesting to note that the aluminum slid freely, and the copper curve rose sharply, at the same value of θ_R at which the two steel curves crossed. Again it appears that, up to this point, deformation was primarily due to yield in the material, while subsequent failure of the interfacial bonds permitted friction effects to predominate.

Figures IV to XIX indicate that the value of the friction coefficient increases with small increments of slip until the normally expected value is attained, at which point the curve flattens out and free sliding results.

The curves plotted in Figures XVI, XVII, and XIX are all fairly smooth, giving no indication of a transition from interfacial deformation to true slip. The plots on Figures XV and XVIII, in contrast, show prominent breaks and discontinuities in the region below 0.00005 cm of apparent slip. The apparent slip in these cases may be due to slip, deformation of the metal, or combinations of both effects. An accurate evaluation of slip with this apparatus is therefore impossible due to the problem of separating the true slip from the deformations produced by yield effects in the asperities in the metal interfaces.

In evaluating these results, some information on the accuracy of the readings is in order. A discussion of the accuracy of the apparatus follows in Appendix A, Details of Procedure.

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$\psi_0 = \pm 0.00229 \text{ minutes of arc}$$

[illegible]

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions - Elastic Behavior

1. The metal interface does not contribute materially to elastic twist.
2. Elastic deflections of a metal specimen with an interface agree with values computed by elastic theory for a continuous specimen.
3. The deflections predicted by elastic theory are obtained regardless of metal, surface finish, or normal stress selected. (Normal loads applied were selected so that resulting normal stresses were safely below critical range which would cause buckling or compressive failure of the column.)
4. The predicted elastic deflections are obtained in non-ferrous metals even though extension of the metal under load resulted in small concurrent permanent deformations.

B. Conclusions - Frictional Behavior

1. The value of the coefficient of friction was initially low for extremely small values of slip at the interface.
2. The value of the coefficient increased with small increments of slip up to the normally expected value at which point free sliding resulted.

THEORY OF THE EARTH

1. General Principles

The earth is a sphere of radius R and mass M . It is assumed that the earth is a homogeneous sphere of uniform density ρ .

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The earth is a sphere of radius R and mass M .

2. General Principles

The value of the coefficient of friction is

initially 1.0 for a smooth surface and 0.5 for a rough surface.

The value of the coefficient of friction is

initially 1.0 for a smooth surface and 0.5 for a rough surface.

The value of the coefficient of friction is

initially 1.0 for a smooth surface and 0.5 for a rough surface.

3. An exact assessment of the increments of slip at the interface was impossible with this experimental technique, due to small amounts of deformation contributed by yield in the asperities in the metal interface. Notwithstanding this factor, the trend indicated that the coefficient of friction starts from zero for zero values of slip and applied stress, and increases with small increments of slip until the normal value is reached.

C. Recommendations

Due to the consistency of the results, both quantitatively and qualitatively, further investigation of metal interfaces for abnormal elastic twist is not recommended.

This apparatus was not designed for investigation of frictional behavior in the slow speed range; therefore modifications of the equipment are deemed necessary prior to any further investigations of the stick slip phenomena with this basic experimental arrangement.

in cases of emergency, the Government of the United States may, in its discretion, suspend the operation of the provisions of this Act, and may, in its discretion, suspend the operation of the provisions of this Act, and may, in its discretion, suspend the operation of the provisions of this Act.

and for the necessity of the results, both qualitative and quantitative, further investigation of model interest for abnormal kinetic trial is not recommended. This apparatus was not designed for investigation of rotational behavior in the slow speed range. Therefore modification of the equipment was deemed necessary prior to any further investigation of the stick with reference to this basic experimental arrangement.

APPENDIX A
DETAILS OF PROCEDURE

DETAILS OF PROCEDURE

In the redesign of the test apparatus, various schemes for measuring angular twist of the specimen were considered. Selection of an optical lever in lieu of the metal indicator arms of the original apparatus was rejected due to the length of light beam required. This would require excessive floor space for the apparatus or would involve the use of a complex prism system. Distribution of the equipment over a large floor space would present a problem in isolating the apparatus from vibrations imparted by the building structure. Another source of error would be encountered in the resolution of the light image on the measuring scale.

The possibility of utilizing interferometry was investigated. Measurement of exceedingly small angles of twist could be obtained by this means, but the cost and complexity of the apparatus required for this work were greater than warranted.

It was decided that a sufficient increase in the sensitivity of the system could be obtained by use of better materials, measuring equipment, and refinements in the experimental method.

The original apparatus utilized an apparatus having an indicator arm length of 7.5" and an optical vernier in which one scale unit represented 0.001 inch of indicator movement.

Estimating the movement of one indicator arm to ± 0.1 scale unit, the resulting accuracy with two arms would be ± 0.2 scale unit.

Results of Experiments

In the redesign of the test apparatus, various changes
 The necessary repairs listed at the beginning were completed.
 Selection of an optical filter in line with the initial indication
 error of the optical apparatus was rejected due to the length
 of light beam required. This would require extensive filter
 system for the apparatus as would involve the use of a complex
 filter system. Disturbance in the equipment over a large filter
 system would present a problem in isolating the apparatus from
 vibrations caused by the building structure. Another source
 of error would be introduced in the selection of the light
 image on the receiving scale.

The necessity of utilizing interference was investigated.
 Measurement of wavelength could easily be made by the
 method of this experiment, but the need for accuracy of the ap-
 paratus required for this work was greater than anticipated.
 It was decided that a different method in the design
 study of the system could be obtained by use of better mate-
 rials, measuring equipment, and refinements in the experimental
 method.

The original apparatus utilized an interferometer having an
 interferometer arm length of 7.5" and an optical filter in which
 one scale was represented 0.001 inch of interferometer movement.
 Refinement in movement of one interferometer arm to 0.1
 scale unit, the resulting movement with two arms would be
 0.2 scale units.

$$\psi_o = \frac{\psi_s}{R} \times \frac{180}{\pi} \times 60 = \text{observed twist in minutes of arc.}$$

Therefore accuracy of the original apparatus was

$$\psi_o = \pm \frac{0.0002}{7.5} \times 3440 = \pm 0.092 \text{ minutes of arc.}$$

By the use of a microscope equipped with a 10 x objective and an optical micrometer, the accuracy was increased considerably. The use of the light-weight but rigid tubular indicator arms permitted increasing the value of R to 12.328".

Calibration of the optical micrometer against a micrometer stage showed that one micrometer drum unit represented 0.00004101 inch of indicator movement. Estimating the micrometer readings to ± 0.1 drum unit would result in an accuracy in observed deflections of ± 0.2 drum units. Therefore, accuracy of the present apparatus is

$$\psi_o = \pm \frac{0.000008202}{12.33} \times 3440 = \pm 0.002290 \text{ minutes of arc}$$

The value of apparent slip (θ_R) measured with this apparatus is computed as follows: For the C-1018 steel specimen with the outside diameter of 0.2365" and inside diameter of 0.191", the mean radius (r_m) of the specimen is 0.1069".

Therefore

$$\frac{\theta_R}{r_m} = \pm \frac{0.000008202}{12.33}$$

$$\theta_R = \pm 7.10 \times 10^{-8} \text{ inches}$$

$$\theta_R = \pm 1.80 \times 10^{-7} \text{ centimeters}$$

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

The above property of the initial spectrum was

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

By the use of a spectrograph equipped with a 10 ft objective and an elliptical mirror, the spectrum was measured photographically. The use of the light-weight and high vacuum spectrograph provided for the light-weight and high vacuum spectrograph. The use of the light-weight and high vacuum spectrograph provided for the light-weight and high vacuum spectrograph.

Comparison of the present spectrum with a spectrum taken with a spectrograph equipped with a 10 ft objective and an elliptical mirror, the spectrum was measured photographically. The use of the light-weight and high vacuum spectrograph provided for the light-weight and high vacuum spectrograph. The use of the light-weight and high vacuum spectrograph provided for the light-weight and high vacuum spectrograph.

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

The value of k is given by (1) and is measured with this system. The value of k is given by (1) and is measured with this system. The value of k is given by (1) and is measured with this system. The value of k is given by (1) and is measured with this system.

Therefore

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

$$k = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right) = \frac{1}{2} \left(\frac{1}{\lambda} + \frac{1}{\lambda'} \right)$$

and hence

APPENDIX B

SUMMARY OF DATA AND CALCULATIONS

1944

RECEIVED BY THE BUREAU OF THE ARMY

1944

Material: C-1018 Steel

Control Specimen:
(without interface)

$D_o = 0.2365"$

$D_i = 0.191"$

$L = 1.0156"$

$D_o^2 - D_i^2 = 0.01945$

$D_o^4 - D_i^4 = 0.001798$

$A = \frac{\pi}{4}(D_o^2 - D_i^2) = 0.01526$

$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$

$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$

$S_T = 1.475 \times Q_A \text{ psi}$

$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$

$E_s = 12 \times 10^6 \text{ psi}$

$\psi_c = 0.00364 Q_A \text{ min.arc.}$

$\psi_o = 0.01144 \psi_s \text{ min.arc.}$

Run No.1

$F_N = 150 \text{ lb.}$

$S_N = 9850 \text{ psi}$

Run No.2

$F_N = 190.7 \text{ lb.}$

$S_N = 12500 \text{ psi}$

Q_A	S_T	ψ_c	ψ_o
150	221.5	0.547	0.504
300	443	1.093	1.018
450	665	1.640	1.635
600	886	2.185	2.250
750	1107	2.733	2.776
900	1330	3.280	3.380
1050	1550	3.830	- -
1200	1770	4.370	- -

1993-1994

002000

$$\text{APRIL } 1960 = 100$$

$$= \frac{1}{T} (\bar{a}_0 - \bar{a}_0^0) = 0.01236$$

$$\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} \frac{e^{-t^2}}{1+t^2} dt = \frac{\pi}{2}$$

$$C_{\text{eff}} = \frac{C}{\frac{A_0}{A_0 - A_t}} = 0.6 \times 1.21 = 0.73$$

Long, J. A. & J. A. J. 1994

CONCLUSIONS

 $\Delta^H = 100^\circ \text{ J P}^\circ$

1. The object is to

18-120-100

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific requirements of the task.

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SPECIMEN NO.1 (continued)

		<u>Run No.3</u>		<u>Run No.4</u>		<u>Run No.5</u>	
		$F_N = 225.4 \text{ lb.}$		$F_N = 74.91 \text{ lb.}$		$F_N = 111.9 \text{ lb.}$	
		$S_N = 14800 \text{ psi}$		$S_N = 4910 \text{ psi}$		$S_N = 7350 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	ψ_o		
150	221.5	0.547	0.539	0.457	0.515		
300	443	1.093	1.098	1.155	1.109		
450	665	1.640	1.670	- -	1.647		
600	886	2.185	2.210	- -	2.240		
750	1107	2.733	2.820				
900	1330	3.280	3.345				
1050	1550	3.830	3.920				
1200	1770	4.370	4.480				

CHINESE M. Y. (continued)

[illegible]

Specimen No.2

Material: C-1018 Steel

Surface Finish:
As Machined (Lathe)Specimen No.3

Material: C-1018 Steel

Surface Finish:
No.1 Emery Paper

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min.arc.}$$

$$\psi_o = 0.01144 \psi_s \text{ min.arc.}$$

SPECIMEN NO.2

SPECIMEN NO.3

Run No.1Run No.2

$F_N = 251.2 \text{ lb.}$ $F_N = 200.3 \text{ lb.}$ $F_N = 251.2 \text{ lb.}$
 $S_N = 16450 \text{ psi}$ $S_N = 13130 \text{ psi}$ $S_N = 16450 \text{ psi}$

Q_A	S_T	ψ_c	ψ_o	ψ_o	ψ_o
120	177	0.435	0.355	0.435	0.413
240	354	0.8695	0.687	0.918	0.849
360	532	1.304	1.180	1.410	1.260
480	710	1.740	1.662	1.925	1.650
600	886	2.177	2.145	2.315	2.100
720	1065	2.608	2.600	2.760	2.590
840	1243	3.043	3.050	-	3.074
900	1330	3.260	3.234	-	-
960	1420	3.480	3.440	-	-
1080	1595	3.910	3.920	-	-
1200	1770	4.350	4.400	-	4.400
1320	1950	4.780	4.970	-	-

Commodities

5.08 2005

[illegible]

Case Study: Illustration

United States
Library of Congress

[illegible]

SPECIMEN NO. 3

Run No. 3 $F_N = 201.29 \text{ lb.}$ $F_N = 41.3 \text{ kg}$ $S_N = 13200 \text{ psi}$ $S_N = 928 \text{ kg/cm}^2$

Q_A	s_t	ψ_R	θ_R	f	Q_A	s_t	ψ_R	θ_R	f
240	24.9	- - -	- - -	0.0245	1920	199.0	0.459	36.20×10^{-6}	0.1960
360	37.4	- - -	- - -	0.0368	2040	211.5	0.573	"	0.2083
480	49.9	- - -	- - -	0.0490	2160	224.0	0.641	"	0.2206
600	62.3	- - -	- - -	0.0613	2280	236.5	0.802	"	0.2326
720	74.9	0.057	4.50×10^{-6}	0.0736	2400	248.7	0.940	"	0.2450
840	87.5	0.080	6.31	0.0859	2520	261.2	1.110	"	0.2575
960	99.9	0.195	15.38	0.0982	2640	273.5	1.420	"	0.2695
1080	112.0	0.183	14.42	0.1103	2760	293.0	1.432	"	0.2820
1200	124.3	0.206	16.25	0.1225	2880	298.5	1.787	"	0.2940
1320	137.0	0.229	18.06	0.1350	3000	311.0	2.910	"	0.3065
1440	149.4	0.321	25.30	0.1470	3120	323.0	2.945	"	0.3186
1560	161.6	0.344	27.12	0.1593	3240	336.0	3.095	"	0.3310
1680	174.3	0.355	28.00	0.1715	3360	348.5	3.660	"	0.3432
1800	186.6	0.344	27.12	0.1840	3480	361.0	- - -	- - -	0.3560

[illegible]

SPECIMEN NO.3 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

ϕ_A	ψ_R	θ_R	f
240	- - -	- - -	0.0293
360	- - -	- - -	0.0440
480	- - -	- - -	0.0587
600	- - -	- - -	0.0734
720	0.023	1.81×10^{-6}	0.0880
840	0.057	4.50 "	0.1026
960	0.092	7.25 "	0.1172
1080	0.080	6.31 "	0.1320
1200	0.080	6.31 "	0.1466
1320	0.344	27.12 "	0.1613
1440	0.344	27.12 "	0.1760
1560	0.321	25.30 "	0.1906
1680	0.470	37.08 "	0.2050
1800	0.665	52.45 "	0.2200
1920	0.768	60.60 "	0.2345
2040	0.894	70.50 "	0.2492
2160	1.625	128.0 "	0.2640
2280	2.450	193.2 "	0.2785
2400	- - -	- - -	0.2935

SPECIMEN NO.3 (continued)

Run No.5 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7700 \text{ psi}$ $s_n = 542 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	0.172	13.56×10^{-6}	0.042
360	0.183	"	0.063
480	0.149	"	0.084
600	0.275	"	0.105
720	0.218	"	0.126
840	0.321	"	0.147
960	0.332	"	0.168
1080	0.332	"	0.189
1200	0.470	"	0.210
1320	0.665	"	0.231
1440	0.860	"	0.252
1560	1.250	"	0.273
1680	- - -	- - -	0.294

Run No.6 $F_N = 64.8 \text{ lb.}$ $F_N = 29.4 \text{ kg}$ $S_N = 4250 \text{ psi}$ $s_n = 299 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	- - -	- - -	0.0762
360	0.057	4.50×10^{-6}	0.1144
480	0.183	"	0.1522
600	0.218	"	0.1905
720	3.630	"	0.2280
840	- - -	- - -	0.2660

(b) (5) DPP, (b) (5) ACP, (b) (5) RMD

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SPECIMEN NO.4

Material: C-1018 Steel

Surface Finish:
2/0 paper

$$D_o = 0.2365''$$

$$D_i = 0.191''$$

$$L = 1.0078''$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00362 Q_A \text{ min. arc.}$$

$$\psi_c = 0.01144 \psi_s \text{ min. arc.}$$

Run No.1

$$F_N = 81.75 \text{ lb. } F_N = 116.3 \text{ lb. } F_N = 167 \text{ lb.}$$

Run No.2

$$S_N = 5360 \text{ psi } S_N = 7640 \text{ psi } S_N = 10940 \text{ psi}$$

Run No.3

Q_A	S_T	ψ_c	ψ_o	ψ_o	ψ_o
120	177	0.4345	0.619	0.389	0.447
240	354	0.8695	1.317	0.953	0.825
300	443	1.090	- - -	1.304	- - -
360	532	1.304	- - -	- - -	1.237
420	620	1.520	- - -	- - -	- - -
480	710	1.740	- - -	- - -	1.674
600	886	2.177	- - -	- - -	2.200
720	1065	2.608	- - -	- - -	2.650
840	1243	3.040	- - -	- - -	3.200
900	1330	3.260	- - -	- - -	- - -
960	1420	3.470	- - -	- - -	- - -
1020	1505	3.690	- - -	- - -	- - -
1080	1595	3.910	- - -	- - -	- - -
1140	1680	4.130	- - -	- - -	- - -
1200	1770	4.350	- - -	- - -	- - -
1320	1950	4.775	- - -	- - -	- - -

SPECIMEN NO.4 (continued)

<u>Run No.4</u>				<u>Run No.5</u>				<u>Run No.6</u>			
$F_N = 200.3 \text{ lb.}$				$F_N = 200.3 \text{ lb.}$				$F_N = 251.2 \text{ lb.}$			
$S_N = 13130 \text{ psi}$				$S_N = 13130 \text{ psi}$				$S_N = 16450 \text{ psi}$			
Q_A	S_T	ψ_c	ψ_o	ψ_o	ψ_o	ψ_o	ψ_o	ψ_o	ψ_o	ψ_o	ψ_o
120	177	0.4345	0.526	0.367	0.378	0.378	0.378	0.378	0.378	0.378	0.378
240	354	0.8695	0.814	0.780	0.860	0.860	0.860	0.860	0.860	0.860	0.860
300	443	1.090	0.953	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
360	532	1.304	- - -	1.204	1.225	1.225	1.225	1.225	1.225	1.225	1.225
420	620	1.520	1.306	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
480	710	1.740	- - -	1.660	1.706	1.706	1.706	1.706	1.706	1.706	1.706
600	886	2.177	2.085	2.061	2.130	2.130	2.130	2.130	2.130	2.130	2.130
720	1065	2.608	2.520	2.400	2.590	2.590	2.590	2.590	2.590	2.590	2.590
840	1243	3.040	- - -	2.956	3.050	3.050	3.050	3.050	3.050	3.050	3.050
900	1330	3.260	3.130	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
960	1420	3.470	- - -	3.370	3.525	3.525	3.525	3.525	3.525	3.525	3.525
1020	1505	3.690	3.670	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
1080	1595	3.910	- - -	3.850	4.000	4.000	4.000	4.000	4.000	4.000	4.000
1140	1680	4.130	4.260	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
1200	1770	4.350	- - -	4.275	4.340	4.340	4.340	4.340	4.340	4.340	4.340
1320	1950	4.775	- - -	- - -	4.765	4.765	4.765	4.765	4.765	4.765	4.765

SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish:
4/0 paper

$$D_o = 0.2365''$$

$$D_i = 0.191''$$

$$L = 1.0078''$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = 0.01526 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = 0.00362 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 116.3 \text{ lb.}$$

$$S_N = 7640 \text{ psi}$$

Run No.2

$$F_N = 167 \text{ lb.}$$

$$S_N = 10940 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o	ψ_o
120	177	0.4345	0.378	0.446
150	221	0.543	- - -	- - -
240	354	0.8695	0.836	0.940
300	443	1.090	- - -	- - -
360	532	1.304	1.237	1.443
450	664	1.627	- - -	- - -
480	710	1.740	1.750	1.912
600	886	2.177	2.154	2.300
720	1065	2.608	2.610	2.656
750	1105	2.714	- - -	- - -
840	1243	3.040	3.120	3.208
900	1330	3.260	- - -	- - -
960	1420	3.470	3.640	3.676
1050	1550	3.800	- - -	- - -
1080	1595	3.910	- - -	- - -
1200	1770	4.350	- - -	4.420
1320	1950	4.775	- - -	- - -
1350	1990	4.885	- - -	- - -

Food & Drug Administration

1998

 $0^{\circ} = 0^{\circ}57'21''$
$$m^2 = 0.7074$$
 $\mu = 1.0054$
$$E_{\text{eff}} = E_0 + \frac{1}{2} \frac{E_0^2}{E_0 + E_0^2}$$
$$E_{\text{eff}} = 0.0075 \text{ eV}$$
 $\mu = 0.01250 \text{ m}^2/\text{s}$

10

Fig. 2. $\Sigma T_{2.1} = 0.04$

 $\phi = \text{angle between } \vec{\mu} \text{ and } \vec{B}$

SPECIMEN NO. 5 (continued)

		<u>Run No. 3</u>		<u>Run No. 4</u>	
		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 14350 \text{ psi}$		$S_N = 16450 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
120	177	0.4345	0.344	- - -	
150	221	0.543	- - -	0.493	
240	354	0.8695	0.847	- - -	
300	443	1.090	- - -	1.040	
360	532	1.304	1.340	- - -	
450	664	1.627	- - -	1.615	
480	710	1.740	1.730	- - -	
600	886	2.177	2.185	2.185	
720	1065	2.608	2.635	- - -	
750	1105	2.714	- - -	2.760	
840	1243	3.040	3.080	- - -	
900	1330	3.260	- - -	3.332	
960	1420	3.470	3.550	- - -	
1050	1550	3.800	- - -	3.800	
1080	1595	3.910	4.020	- - -	
1200	1770	4.350	4.465	4.500	
1320	1950	4.775	4.930	- - -	
1350	1990	4.885	- - -	5.020	

SPECIMEN NO. 5

Run No. 5

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11020 \text{ psi}$$

$$s_n = 775 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
240	24.9	- - -	- - -	0.0293
360	37.4	- - -	- - -	0.0440
480	49.9	- - -	- - -	0.0587
600	62.3	- - -	- - -	0.0734
720	74.9	- - -	- - -	0.0880
840	87.5	- - -	- - -	0.1026
960	99.9	0.069	5.44×10^{-6}	0.1172
1080	112.0	0.069	5.44 "	0.1320
1200	124.3	0.114	8.98 "	0.1466
1320	137.0	0.151	11.90 "	0.1613
1440	149.4	0.218	17.16 "	0.1760
1560	161.6	0.264	20.80 "	0.1906
1680	174.3	0.447	35.25 "	0.2050
1800	186.6	0.734	57.80 "	0.2200

λ	λ^0	λ^1	λ^2	λ^3
1980.0	- - -	- - -	7.54	745
2000.0	- - -	- - -	4.74	230
2100.0	- - -	- - -	0.91	091
2200.0	- - -	- - -	1.95	204
2300.0	- - -	- - -	7.47	737
2400.0	- - -	- - -	1.74	174
2500.0	- - -	- - -	0.17	017
2600.0	- - -	- - -	0.17	017
2700.0	- - -	- - -	0.17	017
2800.0	- - -	- - -	0.17	017
2900.0	- - -	- - -	0.17	017
3000.0	- - -	- - -	0.17	017
3100.0	- - -	- - -	0.17	017
3200.0	- - -	- - -	0.17	017
3300.0	- - -	- - -	0.17	017
3400.0	- - -	- - -	0.17	017
3500.0	- - -	- - -	0.17	017
3600.0	- - -	- - -	0.17	017
3700.0	- - -	- - -	0.17	017
3800.0	- - -	- - -	0.17	017
3900.0	- - -	- - -	0.17	017
4000.0	- - -	- - -	0.17	017
4100.0	- - -	- - -	0.17	017
4200.0	- - -	- - -	0.17	017
4300.0	- - -	- - -	0.17	017
4400.0	- - -	- - -	0.17	017
4500.0	- - -	- - -	0.17	017
4600.0	- - -	- - -	0.17	017
4700.0	- - -	- - -	0.17	017
4800.0	- - -	- - -	0.17	017
4900.0	- - -	- - -	0.17	017
5000.0	- - -	- - -	0.17	017
5100.0	- - -	- - -	0.17	017
5200.0	- - -	- - -	0.17	017
5300.0	- - -	- - -	0.17	017
5400.0	- - -	- - -	0.17	017
5500.0	- - -	- - -	0.17	017
5600.0	- - -	- - -	0.17	017
5700.0	- - -	- - -	0.17	017
5800.0	- - -	- - -	0.17	017
5900.0	- - -	- - -	0.17	017
6000.0	- - -	- - -	0.17	017
6100.0	- - -	- - -	0.17	017
6200.0	- - -	- - -	0.17	017
6300.0	- - -	- - -	0.17	017
6400.0	- - -	- - -	0.17	017
6500.0	- - -	- - -	0.17	017
6600.0	- - -	- - -	0.17	017
6700.0	- - -	- - -	0.17	017
6800.0	- - -	- - -	0.17	017
6900.0	- - -	- - -	0.17	017
7000.0	- - -	- - -	0.17	017
7100.0	- - -	- - -	0.17	017
7200.0	- - -	- - -	0.17	017
7300.0	- - -	- - -	0.17	017
7400.0	- - -	- - -	0.17	017
7500.0	- - -	- - -	0.17	017
7600.0	- - -	- - -	0.17	017
7700.0	- - -	- - -	0.17	017
7800.0	- - -	- - -	0.17	017
7900.0	- - -	- - -	0.17	017
8000.0	- - -	- - -	0.17	017
8100.0	- - -	- - -	0.17	017
8200.0	- - -	- - -	0.17	017
8300.0	- - -	- - -	0.17	017
8400.0	- - -	- - -	0.17	017
8500.0	- - -	- - -	0.17	017
8600.0	- - -	- - -	0.17	017
8700.0	- - -	- - -	0.17	017
8800.0	- - -	- - -	0.17	017
8900.0	- - -	- - -	0.17	017
9000.0	- - -	- - -	0.17	017
9100.0	- - -	- - -	0.17	017
9200.0	- - -	- - -	0.17	017
9300.0	- - -	- - -	0.17	017
9400.0	- - -	- - -	0.17	017
9500.0	- - -	- - -	0.17	017
9600.0	- - -	- - -	0.17	017
9700.0	- - -	- - -	0.17	017
9800.0	- - -	- - -	0.17	017
9900.0	- - -	- - -	0.17	017
10000.0	- - -	- - -	0.17	017

SPECIMEN NO.5 (continued)

Run No.6

$F_N = 117.41 \text{ lb.}$

$F_N = 53.3 \text{ kg}$

$S_N = 770 \text{ psi}$

$s_n = 542 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	- - -	- - -	- - -
360	0.034	2.68×10^{-6}	0.042
480	0.046	3.63	0.063
600	0.218	17.20	0.084
720	0.183	14.42	0.105
840	0.367	28.90	0.126
960	0.458	36.10	0.147
1080	0.780	61.50	0.168
1200	1.075	84.70	0.189
1320	1.396	109.80	0.210
1440	1.775	139.80	0.231
1560	- - -	- - -	0.252

Run No.7

$F_N = 64.78 \text{ lb.}$

$F_N = 29.4 \text{ kg}$

$S_N = 4250 \text{ psi}$

$s_n = 299 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
240	0.183	14.42×10^{-6}	0.076
360	0.183	14.42	0.114
480	0.412	32.50	0.152
600	0.734	57.80	0.191
720	0.734	57.80	0.228
840	0.768	60.60	0.266
960	1.752	138.2	0.305

(newifree) 6.08 newifree

Final Data

$$100 \text{ mV} = 10^3$$

$$10 \text{ mV} = 10^2$$

$$100 \text{ mV} = 10^3$$

$$100 \text{ mV} = 10^3$$

10^3	10^2	10^1	10^0
200.0	10.0	10.0	10.0
100.0	10.0	10.0	10.0
50.0	10.0	10.0	10.0
20.0	10.0	10.0	10.0
10.0	10.0	10.0	10.0
5.0	10.0	10.0	10.0
2.0	10.0	10.0	10.0
1.0	10.0	10.0	10.0

Final Data

$$100 \text{ mV} = 10^3$$

$$10 \text{ mV} = 10^2$$

$$100 \text{ mV} = 10^3$$

$$100 \text{ mV} = 10^3$$

10^3	10^2	10^1	10^0
200.0	10.0	10.0	10.0
100.0	10.0	10.0	10.0
50.0	10.0	10.0	10.0
20.0	10.0	10.0	10.0
10.0	10.0	10.0	10.0
5.0	10.0	10.0	10.0
2.0	10.0	10.0	10.0
1.0	10.0	10.0	10.0

SPECIMEN NO.6

Material: A-4140 Steel

Control Specimen
(without interface)

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 0.9063"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.684 Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00382 Q_A$$

$$E_s = 11.9 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 251.2 \text{ lb.}$$

$$S_N = 18700 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o
120	202.3	0.458	0.493
240	405	0.916	0.952
360	606.5	1.374	1.410
480	810	1.830	1.845
600	1010	2.290	2.315
720	1213	2.746	2.808
840	1416	3.205	3.323
960	1620	3.660	3.736
1080	1820	4.125	4.160

Run No.2

$$F_N = 200.2 \text{ lb.}$$

$$S_N = 14900 \text{ psi}$$

Q_A	S_T	ψ_c	ψ_o
150	252.6	0.573	0.596
300	506	1.145	1.065
450	759	1.720	1.592
600	1010	2.290	2.200
750	1263	2.865	2.740
900	1516	3.440	3.320

3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700
3.700	3.700	3.700	3.700

$\rho = 1000 \text{ kg/m}^3$

$\mu = 0.01 \text{ Pa}\cdot\text{s}$

Assume

1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.000	1.000	1.000	1.000

$\rho = 1000 \text{ kg/m}^3$

$\mu = 0.01 \text{ Pa}\cdot\text{s}$

Assume

0.01 0.01 0.01

$$\rho = 1000 \text{ kg/m}^3$$

$$\mu = 0.01 \text{ Pa}\cdot\text{s}$$

$$\rho = 1000 \text{ kg/m}^3$$

$$\mu = 0.01 \text{ Pa}\cdot\text{s}$$

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$$\mu = 0.01 \text{ Pa}\cdot\text{s}$$

$$\rho = 1000 \text{ kg/m}^3$$

$$\mu = 0.01 \text{ Pa}\cdot\text{s}$$

$$\rho = 1000 \text{ kg/m}^3$$

$$\mu = 0.01 \text{ Pa}\cdot\text{s}$$

SPECIMEN NO.7

Material: A-4140 Steel

Surface Finish
As machined (lathe)

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

				<u>Run No.1</u>		<u>Run No.2</u>	
				$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
				$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
Q_A	S_T	ψ_c		ψ_o		ψ_o	
120	202	0.510		0.367		0.436	
240	404	1.020		0.849		0.895	
300	505	1.274		- - -		- - -	
360	606	1.530		1.410		1.490	
420	706	1.785		- - -		- - -	
480	808	2.040		1.937		2.140	
600	1010	2.546		2.510		2.720	
720	1212	3.057		- - -		3.370	
900	1515	3.820		- - -		- - -	
1020	1718	4.340		- - -		- - -	

RESIDUALS

Least Squares Method

Adjusted R-squared

$$R^2_{adj} = 1 - \frac{(1 - R^2)(n + 1)}{n - k - 1}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(100 + 1)}{100 - 5 - 1}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

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$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

$$R^2_{adj} = 1 - \frac{(1 - 0.9999)(101)}{94}$$

Adjusted R-squared

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

$$R^2_{adj}$$

SPECIMEN NO.7 (continued)

Run No.2		Run No.4	
$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o
120	202	0.510	0.435
240	404	1.020	- - -
300	505	1.274	1.237
360	606	1.530	- - -
420	706	1.785	1.753
480	808	2.040	- - -
600	1010	2.546	2.450
720	1212	3.057	3.092
900	1515	3.820	4.075
1020	1718	4.340	- - -

SPECIMEN NO. 8

Material: A-4140 Steel

Surface Finish:
No.1 emery paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.0177$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342} \text{ psi}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

		<u>Run No.1</u>		<u>Run No.2</u>	
		$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
		$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
150	252.5	0.637	0.618	0.676	
300	505	1.274	1.270	1.330	
450	758	1.910	1.890	1.923	
600	1010	2.546	2.576	2.550	
750	1262	3.185	3.260	3.170	
900	1515	3.820	- - -	- - -	
1050	1770	4.460	- - -	- - -	

SPECIMEN NO. 8 (continued)

				<u>Run No. 3</u>		<u>Run No. 4</u>	
				$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
				$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o		ψ_o	
150	252.5	0.637	0.551	0.585			
300	505	1.274	1.250	1.144			
450	758	1.910	2.042	1.846			
600	1010	2.546	2.520	2.510			
750	1262	3.185	3.164	3.290			
900	1515	3.820	3.890	3.900			
1050	1770	4.460	- - -	4.510			

1000	1330	0.492	0.000	0.000
800	1272	0.480	0.000	0.000
600	1212	0.462	0.000	0.000
400	1152	0.442	0.000	0.000
200	1092	0.422	0.000	0.000
100	1032	0.402	0.000	0.000
50	972	0.382	0.000	0.000
25	912	0.362	0.000	0.000
12.5	852	0.342	0.000	0.000
6.25	792	0.322	0.000	0.000
3.125	732	0.302	0.000	0.000
1.5625	672	0.282	0.000	0.000
0.78125	612	0.262	0.000	0.000
0.390625	552	0.242	0.000	0.000
0.1953125	492	0.222	0.000	0.000
0.09765625	432	0.202	0.000	0.000
0.048828125	372	0.182	0.000	0.000
0.0244140625	312	0.162	0.000	0.000
0.01220703125	252	0.142	0.000	0.000
0.006103515625	192	0.122	0.000	0.000
0.0030517578125	132	0.102	0.000	0.000
0.00152587890625	72	0.082	0.000	0.000
0.000762939453125	12	0.062	0.000	0.000
0.0003814697265625	2	0.042	0.000	0.000

$\log_{10} 2 = 0.30103$
 $\log_{10} 3 = 0.47712$
 $\log_{10} 5 = 0.69897$
 $\log_{10} 7 = 0.84510$
 $\log_{10} 11 = 1.04139$
 $\log_{10} 13 = 1.11394$
 $\log_{10} 17 = 1.23045$
 $\log_{10} 19 = 1.27919$
 $\log_{10} 23 = 1.36173$
 $\log_{10} 29 = 1.46239$
 $\log_{10} 31 = 1.49136$
 $\log_{10} 37 = 1.56820$
 $\log_{10} 41 = 1.61278$
 $\log_{10} 43 = 1.63347$
 $\log_{10} 47 = 1.67209$
 $\log_{10} 53 = 1.72421$
 $\log_{10} 59 = 1.77085$
 $\log_{10} 61 = 1.78533$
 $\log_{10} 67 = 1.82607$
 $\log_{10} 71 = 1.85126$
 $\log_{10} 73 = 1.86332$
 $\log_{10} 79 = 1.89794$
 $\log_{10} 83 = 1.91908$
 $\log_{10} 89 = 1.94939$
 $\log_{10} 97 = 1.99123$

SPECIMEN NO.8

Run No.7

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 15000 \text{ psi}$$

$$s_n = 1053 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	14.2	- - -	- - -	0.0124
240	28.4	- - -	- - -	0.0299
360	42.6	- - -	- - -	0.0373
480	56.8	- - -	- - -	0.0597
600	71.0	- - -	- - -	0.0621
720	85.3	- - -	- - -	0.0746
840	99.5	- - -	- - -	0.0870
960	113.5	0.011	0.86×10^{-6}	0.0995
1080	127.7	0.046	3.59 "	0.1119
1200	142.0	0.057	4.45 "	0.1242
1320	156.2	0.092	7.18 "	0.1367
1440	170.4	0.092	7.18 "	0.1490
1560	184.5	0.138	10.75 "	0.1615
1680	198.7	0.252	19.65 "	0.1740
1800	213.0	0.412	32.15 "	0.1864
1920	227.0	0.803	62.60 "	0.1990
2040	241.0	0.859	67.00 "	0.2113
2160	256.0	1.512	118.0 "	0.2240
2280	270.0	2.660	207.4 "	0.2360
2400	284.0	- - -	- - -	0.2485

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

TABLE 1

	x^0	x^1	x^2	x^3
1000.0	— — —	— — —	1.000	0.000
2000.0	— — —	— — —	1.000	0.000
3000.0	— — —	— — —	1.000	0.000
4000.0	— — —	— — —	1.000	0.000
5000.0	— — —	— — —	1.000	0.000
6000.0	— — —	— — —	1.000	0.000
7000.0	— — —	— — —	1.000	0.000
8000.0	— — —	— — —	1.000	0.000
9000.0	— — —	— — —	1.000	0.000
10000.0	— — —	— — —	1.000	0.000
11000.0	— — —	— — —	1.000	0.000
12000.0	— — —	— — —	1.000	0.000
13000.0	— — —	— — —	1.000	0.000
14000.0	— — —	— — —	1.000	0.000
15000.0	— — —	— — —	1.000	0.000
16000.0	— — —	— — —	1.000	0.000
17000.0	— — —	— — —	1.000	0.000
18000.0	— — —	— — —	1.000	0.000
19000.0	— — —	— — —	1.000	0.000
20000.0	— — —	— — —	1.000	0.000
21000.0	— — —	— — —	1.000	0.000
22000.0	— — —	— — —	1.000	0.000
23000.0	— — —	— — —	1.000	0.000
24000.0	— — —	— — —	1.000	0.000
25000.0	— — —	— — —	1.000	0.000
26000.0	— — —	— — —	1.000	0.000
27000.0	— — —	— — —	1.000	0.000
28000.0	— — —	— — —	1.000	0.000
29000.0	— — —	— — —	1.000	0.000
30000.0	— — —	— — —	1.000	0.000

Run No.8 $F_N = 168.16 \text{ lb.}$ $F_N = 76.4 \text{ kg}$ $S_N = 12540 \text{ psi}$ $s_n = 883 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f	Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0149	120	- - -	- - -	0.0213
240	- - -	- - -	0.0298	240	- - -	- - -	0.0426
360	- - -	- - -	0.0446	360	0.138	10.75×10^{-6}	0.0640
480	- - -	- - -	0.0595	480	0.252	"	0.0852
600	0.114	8.89×10^{-6}	0.0745	600	0.653	"	0.1066
720	0.401	31.25	0.0894	720	1.042	"	0.1280
840	0.481	37.50	0.1042	840	1.820	"	0.1492
960	0.905	70.60	0.1190	960	3.240	"	0.1705
1080	0.974	76.00	0.1340	1080	- - -	- - -	0.1916
1200	0.940	73.35	0.1487				
1320	1.132	88.30	0.1636				
1440	1.317	102.6	0.1786				
1560	1.545	120.5	0.1935				
1680	2.395	186.6	0.2085				
1800	2.575	200.8	0.2232				
1920	2.740	214.0	0.2380				
2040	3.045	237.5	0.2530				
2160	5.440	424.0	0.2680				
2280	- - -	- - -	0.2830				

Run No.9 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 8760 \text{ psi}$ $s_n = 616 \text{ kg/cm}^2$

120	- - -	- - -	0.0213
240	- - -	- - -	0.0426
360	0.138	10.75×10^{-6}	0.0640
480	0.252	"	0.0852
600	0.653	"	0.1066
720	1.042	"	0.1280
840	1.820	"	0.1492
960	3.240	"	0.1705
1080	- - -	- - -	0.1916

SPECIMEN NO.8 (continued)

Run No.10

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4835 \text{ psi}$$

$$s_n = 340 \text{ kg/cm}^2$$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0386
240	0.172	13.40×10^{-6}	0.0773
360	0.836	65.20 "	0.1160
480	8.850	690.0 "	0.1545
600	- - -	- - -	0.1930

(Continued) R. M. H. H. H. H. H.

1911-1912

1911-1912

1911-1912

1911-1912

1911-1912

1	2	3	4
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912
1911-1912	1911-1912	1911-1912	1911-1912

SPECIMEN NO.9

Material: A-4140 Steel

Surface Finish:
2/0 paper

$$D_o = 0.2315"$$

$$D_i = 0.191"$$

$$L = 1.0078"$$

$$D_o^2 - D_i^2 = 0.01711$$

$$D_o^4 - D_i^4 = 0.001542$$

$$A = 0.01342 \text{ in}^2$$

$$S_N = \frac{F_N}{0.01342}$$

$$S_T = 1.684 \times Q_A \text{ psi}$$

$$\psi_c = 0.00425 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

<u>Run No.1</u>		<u>Run No.2</u>	
$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$	
$S_N = 8700 \text{ psi}$		$S_N = 12470 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o
150	252.5	0.637	0.425
300	505	1.274	1.240
450	758	1.910	1.800
600	1010	2.546	2.363
750	1262	3.185	2.910
900	1515	3.820	3.650
1050	1770	4.460	4.410

SPECIMEN NO. 9 (continued)

		<u>Run No. 3</u>		<u>Run No. 4</u>	
		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
		$S_N = 14950 \text{ psi}$		$S_N = 18740 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o	ψ_o	
150	252.5	0.637	0.551	0.768	
300	505	1.274	1.390	1.240	
450	758	1.910	1.893	2.009	
600	1010	2.546	2.480	2.560	
750	1262	3.185	3.020	3.155	
900	1515	3.820	3.760	- - -	
1050	1770	4.460	- - -	- - -	

SPECIMEN NO. 10.

Material: 2S Aluminum

Control Specimen:
(without interface)

$$D_o = 0.2365"$$

$$D_i = 0.191"$$

$$L = 0.9844"$$

$$D_o^2 - D_i^2 = 0.01945$$

$$D_o^4 - D_i^4 = 0.001798$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01526$$

$$S_N = \frac{F_N}{A} = \frac{F_N}{0.01526} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q_A$$

$$S_T = 1.475 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times C_A}{(D_o^4 - D_i^4) \times E_s}$$

$$E_s = 3.7 \times 10^6 \text{ psi}$$

$$\psi_c = 0.01145 \times C_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No. 1

$$F_N = 116.3 \text{ lb.}$$

$$S_N = 7640 \text{ psi}$$

$$\psi_o$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$\psi_R$$

$$\psi_o$$

$$\psi_R$$

Run No. 2

$$F_N = 167 \text{ lb.}$$

$$S_N = 10940 \text{ psi}$$

$$\psi_o$$

$$\psi_c$$

$$S_T$$

$$Q_A$$

$$\psi_R$$

$$\psi_o$$

$$\psi_R$$

ψ_R = Residual Twist.

Sight edges on indicator arms failed to return to zero index on removal of torque. ψ_R is residual twist remaining in specimen after removal of torque.

Small Area

Large Area

$$A^2 = B^2 + C^2$$

$$A^2 = B^2 + C^2$$

$$2 \log 0.0000000000000000$$

$$2 \log 0.0000000000000000$$

$$A^2 = B^2 + C^2$$

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$$A^2 = B^2 + C^2$$

Small Area

Large Area

$$A^2 = B^2 + C^2$$

$$A^2 = B^2 + C^2$$

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$$A^2 = B^2 + C^2$$

$$A^2 = B^2 + C^2$$

$$A^2 = B^2 + C^2$$

SPECIMEN NO.11

Material: Copper

Control Specimen:
(without interface)

$$D_o = 0.2368''$$

$$D_i = 0.191''$$

$$L = 1.01563''$$

$$D_o^2 - D_i^2 = 0.01959$$

$$D_o^4 - D_i^4 = 0.001814$$

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) = 0.01537$$

$$S_N = \frac{F_N}{0.01537} \text{ psi}$$

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} Q_A$$

$$S_T = 1.464 \times Q_A \text{ psi}$$

$$\psi_c = \frac{77.3 \times L \times Q_A}{(D_o^4 - D_i^4) \times E_s}$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_c = 0.00722 Q_A$$

$$\psi_o = 0.01144 \psi_s$$

Run No.1

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

$$\psi_o$$

$$Q_A$$

$$S_T$$

$$\psi_c$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

Run No.2

$$F_N = 250 \text{ lb.}$$

$$S_N = 16270 \text{ psi}$$

Run No.3

$$F_N = 200 \text{ lb.}$$

$$S_N = 13020 \text{ psi}$$

$$\psi_R$$

$$Q_A$$

$$\psi_R$$

$$\psi_R$$

SPECIMEN NO.12

Run No.1

$$F_N = 31.86 \text{ lb.}$$

$$F_N = 14.4 \text{ kg}$$

$$S_N = 2375 \text{ psi}$$

$$s_n = 167 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	14.2	- - -	- - -	0.0785
240	28.4	0.046	3.59×10^{-6}	0.1570
360	42.6	0.149	11.60 "	0.2358
480	56.8	0.825	64.40 "	0.3140
600	71.0	- - -	- - -	0.3930
720	85.3			
840	99.5			
960	113.5			
1080	127.7			
1200	142.0			
1320	156.2			
1440	170.4			
1560	184.5			
1680	198.7			
1800	213.0			

Material: A-4140 Steel

Surface Finish: 4/0 paper

Material: A-1140 Steel
Surface Finish: 4/0 Paper

SPECIMEN NO.12 (continued)

Run No.2 $F_N = 53.8 \text{ lb.}$ $F_N = 24.2 \text{ kg}$ $S_N = 3980 \text{ psi}$ $s_n = 280 \text{ kg/cm}^2$

Q_A	ψ_R	σ_R	f
120	0.114	8.89×10^{-6}	0.0469
240	0.184	14.34	0.0938
360	0.321	25.05	0.1406
480	0.860	67.15	0.1875
600	2.580	201.3	0.2344
720	3.085	240.6	0.2814
840	- - -	- - -	0.3280

Run No.3 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 8760 \text{ psi}$ $s_n = 616 \text{ kg/cm}^2$

Q_A	ψ_R	σ_R	f
120	- - -	- - -	0.0213
240	- - -	- - -	0.0426
360	0.011	0.86×10^{-6}	0.0640
480	0.046	3.59	0.0862
600	0.184	14.34	0.1066
720	0.665	51.90	0.1280
840	0.688	53.65	0.1492
960	0.872	68.00	0.1705
1080	1.053	82.20	0.1916
1200	1.144	89.30	0.2130
1320	1.707	133.0	0.2340
1440	2.096	163.3	0.2555
1560	3.060	238.6	0.2768
1680	7.550	589.0	0.2980
1800	- - -	- - -	0.3190

(continued) 31-bit addresses

Level 000

$$+1/2 \Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

$$\Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

$$\Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

$$\Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

1

$$\Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

8120.0

8000.0

$$\Delta A_{000} = \frac{1}{2} \Delta A_{000}$$

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

Level 001

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

2

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

$$\Delta A_{001} = \frac{1}{2} \Delta A_{001}$$

8120.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

8000.0

[illegible]

SPECIMEN NO.13

Run No.1

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
60	6.3	- - -	- - -	0.0074
120	12.6	0.080	6.34×10^{-6}	0.0147
180	18.9	0.103	8.15 "	0.0220
240	25.2	0.114	9.04 "	0.0294
300	31.5	- - -	- - -	0.0367

Run No.5

$$F_N = 117.41 \text{ lb.}$$

$$F_N = 53.3 \text{ kg}$$

$$S_N = 7800 \text{ psi}$$

$$s_n = 548 \text{ kg/cm}^2$$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	0.023	1.81×10^{-6}	0.0421
360	0.126	9.95 "	0.0632
480	0.149	11.76 "	0.0842
600	0.183	14.45 "	0.1052
720	0.298	23.50 "	0.1264
840	- - -	- - -	0.1475

SPECIMEN NO.13 (continued)

Run No.2 $F_N = 201.29 \text{ lb.}$ $F_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f	Q_A	ψ_R	θ_R	f
60	-	-	0.00615	120	-	-	0.0098
120	-	-	0.0123	240	-	-	0.0197
180	0.149	11.76×10^{-6}	0.0184	360	0.114	9.00×10^{-6}	0.0295
240	0.069	5.42	0.0246	480	0.046	3.62	0.0394
300	0.149	11.76	0.0308	600	0.183	14.45	0.0493
360	0.137	10.85	0.0369	720	0.435	34.40	0.0640
420	0.309	24.40	0.0430	840	0.618	48.80	0.0690
480	0.275	21.72	0.0491	960	-	-	-
540	0.286	22.60	0.0553				
600	0.367	29.00	0.0615				
660	0.458	36.20	0.0676				
720	0.435	34.40	0.0737				
780	0.435	34.40	0.0800				
840	0.446	35.22	0.0860				
960	-	-	-				

Run No.3 $F_N = 251 \text{ lb.}$ $F_N = 114.0 \text{ kg}$ $S_N = 16700 \text{ psi}$ $s_n = 1172 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	-	-	0.0098
240	-	-	0.0197
360	0.114	9.00×10^{-6}	0.0295
480	0.046	"	0.0394
600	0.183	"	0.0493
720	0.435	"	0.0640
840	0.618	"	0.0690
960	-	-	-

(Name/ID) Class Section

Level 1

$$\text{val } 100 = 10^2$$

$$\text{val } 1000 = 10^3$$

$$\text{val } 10000 = 10^4$$

$$\text{val } 100000 = 10^5$$

$$\text{val } 1000000 = 10^6$$

$$\text{val } 10000000 = 10^7$$

$$\text{val } 100000000 = 10^8$$

$$\text{val } 1000000000 = 10^9$$

$$\text{val } 10000000000 = 10^{10}$$

$$\text{val } 100000000000 = 10^{11}$$

$$\text{val } 1000000000000 = 10^{12}$$

$$\text{val } 10000000000000 = 10^{13}$$

$$\text{val } 100000000000000 = 10^{14}$$

$$\text{val } 1000000000000000 = 10^{15}$$

$$\text{val } 10000000000000000 = 10^{16}$$

$$\text{val } 100000000000000000 = 10^{17}$$

$$\text{val } 1000000000000000000 = 10^{18}$$

Level 2

$$\text{val } 100000 = 10^5$$

$$\text{val } 1000000 = 10^6$$

$$\text{val } 10000000 = 10^7$$

$$\text{val } 100000000 = 10^8$$

$$\text{val } 1000000000 = 10^9$$

$$\text{val } 10000000000 = 10^{10}$$

$$\text{val } 100000000000 = 10^{11}$$

$$\text{val } 1000000000000 = 10^{12}$$

$$\text{val } 10000000000000 = 10^{13}$$

$$\text{val } 100000000000000 = 10^{14}$$

$$\text{val } 1000000000000000 = 10^{15}$$

$$\text{val } 10000000000000000 = 10^{16}$$

$$\text{val } 100000000000000000 = 10^{17}$$

$$\text{val } 1000000000000000000 = 10^{18}$$

$$\text{val } 10000000000000000000 = 10^{19}$$

$$\text{val } 100000000000000000000 = 10^{20}$$

$$\text{val } 1000000000000000000000 = 10^{21}$$

$$\text{val } 10000000000000000000000 = 10^{22}$$

$$\text{val } 100000000000000000000000 = 10^{23}$$

$$\text{val } 1000000000000000000000000 = 10^{24}$$

$$\text{val } 10000000000000000000000000 = 10^{25}$$

$$\text{val } 100000000000000000000000000 = 10^{26}$$

$$\text{val } 1000000000000000000000000000 = 10^{27}$$

$$\text{val } 10000000000000000000000000000 = 10^{28}$$

$$\text{val } 100000000000000000000000000000 = 10^{29}$$

$$\text{val } 1000000000000000000000000000000 = 10^{30}$$

$$\text{val } 10000000000000000000000000000000 = 10^{31}$$

$$\text{val } 100000000000000000000000000000000 = 10^{32}$$

$$\text{val } 1000000000000000000000000000000000 = 10^{33}$$

$$\text{val } 10000000000000000000000000000000000 = 10^{34}$$

SPECIMEN NO.13 (continued)

Run No.6 $P_N = 168.16 \text{ lb.}$ $P_N = 76.4 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.092	7.24×10^{-6}	0.0294
360	0.080	6.33 "	0.0441
480	0.057	4.52 "	0.0588
600	0.092	7.24 "	0.0735
720	0.195	15.35 "	0.0882
840	0.481	38.00 "	0.1028
960	0.722	57.00 "	0.1175
1080	0.929	73.30 "	0.1320
1200	- - -	- - -	0.1470

Run No.7 $P_N = 201.29 \text{ lb.}$ $P_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0123
240	0.011	0.90×10^{-6}	0.0246
360	0.092	7.24 "	0.0369
480	0.172	13.56 "	0.0491
600	0.149	11.76 "	0.0615
720	0.218	17.15 "	0.0737
840	0.321	25.30 "	0.0860
960	0.458	36.10 "	0.0983
1080	0.493	38.90 "	0.1105
1200	0.550	43.30 "	0.1228
1320	0.825	65.10 "	0.1350
1440	2.120	167.0 "	0.1473
1560	2.820	222.4 "	0.1596
1680	- - -	- - -	0.1720

SPECIMEN NO.14

Material: Copper

Surface Finish: 2/o Paper

$$D_o = 0.2359"$$

$$D_i = 0.191"$$

$$L = 1.000"$$

$$S_N = \frac{F_N}{0.01505} \text{ psi}$$

$$S_T = 1.495 \times Q_A \text{ psi}$$

$$\psi_c = 0.00708 \times Q_A$$

$$E_s = 6.0 \times 10^6 \text{ psi}$$

$$\psi_o = 0.01144 \psi_s$$

<u>Run No.1</u>		<u>Run No.2</u>	
$F_N = 64.8 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$	
$S_N = 4300 \text{ psi}$		$S_N = 7800 \text{ psi}$	
Q_A	S_T	ψ_c	ψ_o
120	180	0.850	0.756
240	359	1.700	1.560
360	539	2.550	2.510
480	719	3.400	3.480
600	900	4.250	4.500
720	1076	5.100	5.730
840	1257	5.950	5.970
960	1436	6.800	
1080	1614	7.650	

$\Delta G^\circ = -0.0194 \log K$

$$T_{\text{eff}} = \frac{0.05602}{\frac{1}{\text{bar}}}$$

$$T = 1.000$$

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SPECIMEN NO.14 (continued)

<u>Run No.3</u>				<u>Run No.4</u>				<u>Run No.5</u>			
$F_N = 168.2 \text{ lb.}$				$F_N = 201.3 \text{ lb.}$				$F_N = 231.68 \text{ lb.}$			
$S_N = 11170 \text{ psi}$				$S_N = 13360 \text{ psi}$				$S_N = 15400 \text{ psi}$			
Q_A	S_T	ψ_c	ψ_o	Q_A	ψ_o	Q_A	ψ_o	Q_A	ψ_o	Q_A	ψ_o
120	180	0.850	0.733	120	0.780	120	0.882	120	0.882	120	0.882
240	359	1.700	1.525	240	1.696	240	1.294	240	1.294	240	1.294
360	539	2.550	2.350	360	2.570	360	2.610	360	2.610	360	2.610
480	719	3.400	3.080	480	3.475	480	3.540	480	3.540	480	3.540
600	900	4.250	4.040	600	4.290	600	4.380	600	4.380	600	4.380
720	1076	5.100	4.940	720	5.360	720	5.333	720	5.333	720	5.333
840	1257	5.950	5.740	840	6.310	840	6.230	840	6.230	840	6.230
960	1436	6.800	6.720	960	7.230	960	7.250	960	7.250	960	7.250
1080	1614	7.650	-	-	off scope	-	-	-	-	-	-

(Eubank & Eubank) 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 268

2-Cell, 2nd	3-Cell, 2nd	4-Cell, 2nd	5-Cell, 2nd
4F 00.115 = q^5	4F 01.105 = q^4	4F 02.101 = q^3	4F 03.101 = q^2
4F 04.101 = q^2	4F 05.101 = q^2	4F 06.101 = q^2	4F 07.101 = q^2
5F 00.115 = q^5	5F 01.105 = q^4	5F 02.101 = q^3	5F 03.101 = q^2
5F 04.101 = q^2	5F 05.101 = q^2	5F 06.101 = q^2	5F 07.101 = q^2
6F 00.115 = q^5	6F 01.105 = q^4	6F 02.101 = q^3	6F 03.101 = q^2
6F 04.101 = q^2	6F 05.101 = q^2	6F 06.101 = q^2	6F 07.101 = q^2
7F 00.115 = q^5	7F 01.105 = q^4	7F 02.101 = q^3	7F 03.101 = q^2
7F 04.101 = q^2	7F 05.101 = q^2	7F 06.101 = q^2	7F 07.101 = q^2
8F 00.115 = q^5	8F 01.105 = q^4	8F 02.101 = q^3	8F 03.101 = q^2
8F 04.101 = q^2	8F 05.101 = q^2	8F 06.101 = q^2	8F 07.101 = q^2
9F 00.115 = q^5	9F 01.105 = q^4	9F 02.101 = q^3	9F 03.101 = q^2
9F 04.101 = q^2	9F 05.101 = q^2	9F 06.101 = q^2	9F 07.101 = q^2
10F 00.115 = q^5	10F 01.105 = q^4	10F 02.101 = q^3	10F 03.101 = q^2
10F 04.101 = q^2	10F 05.101 = q^2	10F 06.101 = q^2	10F 07.101 = q^2
11F 00.115 = q^5	11F 01.105 = q^4	11F 02.101 = q^3	11F 03.101 = q^2
11F 04.101 = q^2	11F 05.101 = q^2	11F 06.101 = q^2	11F 07.101 = q^2
12F 00.115 = q^5	12F 01.105 = q^4	12F 02.101 = q^3	12F 03.101 = q^2
12F 04.101 = q^2	12F 05.101 = q^2	12F 06.101 = q^2	12F 07.101 = q^2
13F 00.115 = q^5	13F 01.105 = q^4	13F 02.101 = q^3	13F 03.101 = q^2
13F 04.101 = q^2	13F 05.101 = q^2	13F 06.101 = q^2	13F 07.101 = q^2
14F 00.115 = q^5	14F 01.105 = q^4	14F 02.101 = q^3	14F 03.101 = q^2
14F 04.101 = q^2	14F 05.101 = q^2	14F 06.101 = q^2	14F 07.101 = q^2
15F 00.115 = q^5	15F 01.105 = q^4	15F 02.101 = q^3	15F 03.101 = q^2
15F 04.101 = q^2	15F 05.101 = q^2	15F 06.101 = q^2	15F 07.101 = q^2
16F 00.115 = q^5	16F 01.105 = q^4	16F 02.101 = q^3	16F 03.101 = q^2
16F 04.101 = q^2	16F 05.101 = q^2	16F 06.101 = q^2	16F 07.101 = q^2
17F 00.115 = q^5	17F 01.105 = q^4	17F 02.101 = q^3	17F 03.101 = q^2
17F 04.101 = q^2	17F 05.101 = q^2	17F 06.101 = q^2	17F 07.101 = q^2
18F 00.115 = q^5	18F 01.105 = q^4	18F 02.101 = q^3	18F 03.101 = q^2
18F 04.101 = q^2	18F 05.101 = q^2	18F 06.101 = q^2	18F 07.101 = q^2
19F 00.115 = q^5	19F 01.105 = q^4	19F 02.101 = q^3	19F 03.101 = q^2
19F 04.101 = q^2	19F 05.101 = q^2	19F 06.101 = q^2	19F 07.101 = q^2
20F 00.115 = q^5	20F 01.105 = q^4	20F 02.101 = q^3	20F 03.101 = q^2
20F 04.101 = q^2	20F 05.101 = q^2	20F 06.101 = q^2	20F 07.101 = q^2
21F 00.115 = q^5	21F 01.105 = q^4	21F 02.101 = q^3	21F 03.101 = q^2
21F 04.101 = q^2	21F 05.101 = q^2	21F 06.101 = q^2	21F 07.101 = q^2
22F 00.115 = q^5	22F 01.105 = q^4	22F 02.101 = q^3	22F 03.101 = q^2
22F 04.101 = q^2	22F 05.101 = q^2	22F 06.101 = q^2	22F 07.101 = q^2
23F 00.115 = q^5	23F 01.105 = q^4	23F 02.101 = q^3	23F 03.101 = q^2
23F 04.101 = q^2	23F 05.101 = q^2	23F 06.101 = q^2	23F 07.101 = q^2
24F 00.115 = q^5	24F 01.105 = q^4	24F 02.101 = q^3	24F 03.101 = q^2
24F 04.101 = q^2	24F 05.101 = q^2	24F 06.101 = q^2	24F 07.101 = q^2
25F 00.115 = q^5	25F 01.105 = q^4	25F 02.101 = q^3	25F 03.101 = q^2
25F 04.101 = q^2	25F 05.101 = q^2	25F 06.101 = q^2	25F 07.101 = q^2
26F 00.115 = q^5	26F 01.105 = q^4	26F 02.101 = q^3	26F 03.101 = q^2
26F 04.101 = q^2	26F 05.101 = q^2	26F 06.101 = q^2	26F 07.101 = q^2
27F 00.115 = q^5	27F 01.105 = q^4	27F 02.101 = q^3	27F 03.101 = q^2
27F 04.101 = q^2	27F 05.101 = q^2	27F 06.101 = q^2	27F 07.101 = q^2
28F 00.115 = q^5	28F 01.105 = q^4	28F 02.101 = q^3	28F 03.101 = q^2
28F 04.101 = q^2	28F 05.101 = q^2	28F 06.101 = q^2	28F 07.101 = q^2
29F 00.115 = q^5	29F 01.105 = q^4	29F 02.101 = q^3	29F 03.101 = q^2
29F 04.101 = q^2	29F 05.101 = q^2	29F 06.101 = q^2	29F 07.101 = q^2
30F 00.115 = q^5	30F 01.105 = q^4	30F 02.101 = q^3	30F 03.101 = q^2
30F 04.101 = q^2	30F 05.101 = q^2	30F 06.101 = q^2	30F 07.101 = q^2
31F 00.115 = q^5	31F 01.105 = q^4	31F 02.101 = q^3	31F 03.101 = q^2
31F 04.101 = q^2	31F 05.101 = q^2	31F 06.101 = q^2	31F 07.101 = q^2
32F 00.115 = q^5	32F 01.105 = q^4	32F 02.101 = q^3	32F 03.101 = q^2
32F 04.101 = q^2	32F 05.101 = q^2	32F 06.101 = q^2	32F 07.101 = q^2
33F 00.115 = q^5	33F 01.105 = q^4	33F 02.101 = q^3	33F 03.101 = q^2
33F 04.101 = q^2	33F 05.101 = q^2	33F 06.101 = q^2	33F 07.101 = q^2
34F 00.115 = q^5	34F 01.105 = q^4	34F 02.101 = q^3	34F 03.101 = q^2
34F 04.101 = q^2	34F 05.101 = q^2	34F 06.101 = q^2	34F 07.101 = q^2
35F 00.115 = q^5	35F 01.105 = q^4	35F 02.101 = q^3	35F 03.101 = q^2
35F 04.101 = q^2	35F 05.101 = q^2	35F 06.101 = q^2	35F 07.101 = q^2
36F 00.115 = q^5	36F 01.105 = q^4	36F 02.101 = q^3	36F 03.101 = q^2
36F 04.101 = q^2	36F 05.101 = q^2	36F 06.101 = q^2	36F 07.101 = q^2
37F 00.115 = q^5	37F 01.105 = q^4	37F 02.101 = q^3	37F 03.101 = q^2
37F 04.101 = q^2	37F 05.101 = q^2	37F 06.101 = q^2	37F 07.101 = q^2
38F 00.115 = q^5	38F 01.105 = q^4	38F 02.101 = q^3	38F 03.101 = q^2
38F 04.101 = q^2	38F 05.101 = q^2	38F 06.101 = q^2	38F 07.101 = q^2
39F 00.115 = q^5	39F 01.105 = q^4	39F 02.101 = q^3	39F 03.101 = q^2
39F 04.101 = q^2	39F 05.101 = q^2	39F 06.101 = q^2	39F 07.101 = q^2
40F 00.115 = q^5	40F 01.105 = q^4	40F 02.101 = q^3	40F 03.101 = q^2
40F 04.101 = q^2	40F 05.101 = q^2	40F 06.101 = q^2	40F 07.101 = q^2
41F 00.115 = q^5	41F 01.105 = q^4	41F 02.101 = q^3	41F 03.101 = q^2
41F 04.101 = q^2	41F 05.101 = q^2	41F 06.101 = q^2	41F 07.101 = q^2
42F 00.115 = q^5	42F 01.105 = q^4	42F 02.101 = q^3	42F 03.101 = q^2
42F 04.101 = q^2	42F 05.101 = q^2	42F 06.101 = q^2	42F 07.101 = q^2
43F 00.115 = q^5	43F 01.105 = q^4	43F 02.101 = q^3	43F 03.101 = q^2
43F 04.101 = q^2	43F 05.101 = q^2	43F 06.101 = q^2	43F 07.101 = q^2
44F 00.115 = q^5	44F 01.105 = q^4	44F 02.101 = q^3	44F 03.101 = q^2
44F 04.101 = q^2	44F 05.101 = q^2	44F 06.101 = q^2	44F 07.101 = q^2
45F 00.115 = q^5	45F 01.105 = q^4	45F 02.101 = q^3	45F 03.101 = q^2
45F 04.101 = q^2	45F 05.101 = q^2	45F 06.101 = q^2	45F 07.101 = q^2
46F 00.115 = q^5	46F 01.105 = q^4	46F 02.101 = q^3	46F 03.101 = q^2
46F 04.101 = q^2	46F 05.101 = q^2	46F 06.101 = q^2	46F 07.101 = q^2
47F 00.115 = q^5	47F 01.105 = q^4	47F 02.101 = q^3	47F 03.101 = q^2
47F 04.101 = q^2	47F 05.101 = q^2	47F 06.101 = q^2	47F 07.101 = q^2
48F 00.115 = q^5	48F 01.105 = q^4	48F 02.101 = q^3	48F 03.101 = q^2
48F 04.101 = q^2	48F 05.101 = q^2	48F 06.101 = q^2	48F 07.101 = q^2
49F 00.115 = q^5	49F 01.105 = q^4	49F 02.101 = q^3	49F 03.101 = q^2
49F 04.101 = q^2	49F 05.101 = q^2	49F 06.101 = q^2	49F 07.101 = q^2
50F 00.115 = q^5	50F 01.105 = q^4	50F 02.101 = q^3	50F 03.101 = q^2
50F 04.101 = q^2	50F 05.101 = q^2	50F 06.101 = q^2	50F 07.101 = q^2
51F 00.115 = q^5	51F 01.105 = q^4	51F 02.101 = q^3	51F 03.101 = q^2
51F 04.101 = q^2	51F 05.101 = q^2	51F 06.101 = q^2	51F 07.101 = q^2
52F 00.115 = q^5	52F 01.105 = q^4	52F 02.101 = q^3	52F 03.101 = q^2
52F 04.101 = q^2	52F 05.101 = q^2	52F 06.101 = q^2	52F 07.101 = q^2
53F 00.115 = q^5	53F 01.105 = q^4	53F 02.101 = q^3	53F 03.101 = q^2
53F 04.101 = q^2	53F 05.101 = q^2	53F 06.101 = q^2	53F 07.101 = q^2
54F 00.115 = q^5	54F 01.105 = q^4	54F 02.101 = q^3	54F 03.101 = q^2
54F 04.101 = q^2	54F 05.101 = q^2	54F 06.101 = q^2	54F 07.101 = q^2
55F 00.115 = q^5	55F 01.105 = q^4	55F 02.101 = q^3	55F 03.101 = q^2
55F 04.101 = q^2	55F 05.101 = q^2	55F 06.101 = q^2	55F 07.101 = q^2
56F 00.115 = q^5	56F 01.105 = q^4	56F 02.101 = q^3	56F 03.101 = q^2
56F 04.101 = q^2	56F 05.101 = q^2	56F 06.101 = q^2	56F 07.101 = q^2
57F 00.115 = q^5	57F 01.105 = q^4	57F 02.101 = q^3	57F 03.101 = q^2
57F 04.101 = q^2	57F 05.101 = q^2	57F 06.101 = q^2	57F 07.101 = q^2
58F 00.115 = q^5	58F 01.105 = q^4	58F 02.101 = q^3	58F 03.101 = q^2
58F 04.101 = q^2	58F 05.101 = q^2	58F 06.101 = q^2	58F 07.101 = q^2
59F 00.115 = q^5	59F 01.105 = q^4	59F 02.101 = q^3	59F 03.101 = q^2
59F 04.101 = q^2	59F 05.101 = q^2	59F 06.101 = q^2	59F 07.101 = q^2
60F 00.115 = q^5	60F 01.105 = q^4	60F 02.101 = q^3	60F 03.101 = q^2
60F 04.101 = q^2	60F 05.101 = q^2	60F 06.101 = q^2	60F 07.101 = q^2
61F 00.115 = q^5	61F 01.105 = q^4	61F 02.101 = q^3	61F 03.101 = q^2
61F 04.101 = q^2	61F 05.101 = q^2	61F 06.101 = q^2	61F 07.101 = q^2
62F 00.115 = q^5	62F 01.105 = q^4	62F 02.101 = q^3	62F 03.101 = q^2
62F 04.101 = q^2	62F 05.101 = q^2	62F 06.101 = q^2	62F 07.101 = q^2
63F 00.115 = q^5	63F 01.105 = q^4	63F 02.101 = q^3	63F 03.101 = q^2
63F 04.101 = q^2	63F 05.101 = q^2	63F 06.101 = q^2	63F 07.101 = q^2
64F 00.115 = q^5	64F 01.105 = q^4	64F 02.101 = q^3	64F 03.101 = q^2
64F 04.101 = q^2	64F 05.101 = q^2	64F 06.101 = q^2	64F 07.101 = q^2
65F 00.115 = q^5	65F 01.105 = q^4	65F 02.101 = q^3	65F 03.101 = q^2
65F 04.101 = q^2	65F 05.101 = q^2	65F 06.101 = q^2	65

SPECIMEN NO.14

Run No.1

$$F_N = 64.78 \text{ lb.}$$

$$F_N = 29.4 \text{ kg}$$

$$S_N = 4300 \text{ psi}$$

$$s_n = 302 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	ϕ_R	f
120	12.6	- - -	- - -	0.0382
240	25.2	0.183	14.46×10^{-6}	0.0763
360	37.8	0.298	23.50 "	0.1144
480	50.5	0.505	39.88 "	0.1526
600	63.1	3.310	261.5 "	0.1910
720	75.6	- - -	- - -	0.2290
840	88.4			
960	101.0			
1080	113.6			
1200	126.1			
1320	138.9			
1440	151.2			
1560	164.0			
1680	176.6			
1800	189.0			
1920	201.5			
2040	214.2			
2160	226.8			
2280	239.5			
2400	252.0			
2520	264.0			

SPECIMEN NO.14 (continued)

Run No.2 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7800 \text{ psi}$ $s_n = 548 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	0.057	4.50×10^{-6}	0.0421
360	0.184	14.50	0.0632
480	0.378	29.80	0.0842
600	0.653	51.50	0.1052
720	1.032	81.50	0.1264
840	1.420	112.0	0.1475
960	3.370	294.3	0.1683
1080	10.000	790.0	0.1893
1200	- - -	- - -	0.2100

Run No.3 $F_N = 168.16 \text{ lb.}$ $F_N = 764 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0147
240	- - -	- - -	0.0294
360	- - -	- - -	0.0441
480	- - -	- - -	0.0588
600	0.057	4.50×10^{-6}	0.0735
720	0.149	11.76	0.0882
840	0.172	13.56	0.1028
960	0.241	19.00	0.1175
1080	0.355	28.00	0.1320
1200	0.390	30.78	0.1470
1320	0.424	33.24	0.1616
1440	0.734	57.90	0.1764
1560	- - -	- - -	0.1910

East 200

101.01.002 x 10³

40.408 x 10³

100.0000 x 10³

100.0000 x 10³

East 200

101.01.002 x 10³

40.408 x 10³

100.0000 x 10³

100.0000 x 10³

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Run No.4 $F_N = 201.29 \text{ lb.}$ $F_N = 91.3 \text{ kg}$ $S_N = 13360 \text{ psi}$ $s_n = 939 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f	Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0123	120	- - -	- - -	0.0107
240	0.184	14.50×10^{-6}	0.0246	240	0.160	12.62×10^{-6}	0.0214
360	0.264	"	0.0369	360	0.321	"	0.0320
480	0.435	"	0.0491	480	0.424	"	0.0427
600	0.550	"	0.0615	600	0.493	"	0.0535
720	0.723	"	0.0737	720	0.619	"	0.0640
840	0.769	"	0.0860	840	0.756	"	0.0748
960	0.906	"	0.0983	960	0.974	"	0.0855
1080	1.007	"	0.1105	1080	0.962	"	0.0962
1200	1.087	"	0.1228	1200	1.100	"	0.1069
1320	1.363	"	0.1350	1320	1.340	"	0.1175
1440	1.546	"	0.1473	1440	1.350	"	0.1280
1560	2.040	"	0.1596	1560	1.593	"	0.1390
1680	2.222	"	0.1720	1680	1.775	"	0.1495
1800	2.500	"	0.1845	1800	1.890	"	0.1600
1920	2.960	"	0.1966	1920	2.060	"	0.1708
2040	- - -	- - -	0.2090	2040	2.325	"	0.1815

Run No.5 $F_N = 231.68 \text{ lb.}$ $F_N = 105.0 \text{ kg}$ $S_N = 15400 \text{ psi}$ $s_n = 1080 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0107
240	0.160	12.62×10^{-6}	0.0214
360	0.321	"	0.0320
480	0.424	"	0.0427
600	0.493	"	0.0535
720	0.619	"	0.0640
840	0.756	"	0.0748
960	0.974	"	0.0855
1080	0.962	"	0.0962
1200	1.100	"	0.1069
1320	1.340	"	0.1175
1440	1.350	"	0.1280
1560	1.593	"	0.1390
1680	1.775	"	0.1495
1800	1.890	"	0.1600
1920	2.060	"	0.1708
2040	2.325	"	0.1815
2160	2.690	"	0.1920
2280	2.990	"	0.2030
2400	3.350	"	0.2135

SPECIMEN NO.15

Run No.1

$$F_N = 201.29 \text{ lb.}$$

$$F_N = 91.3 \text{ kg}$$

$$S_N = 13360 \text{ psi}$$

$$s_n = 939 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f
120	12.6	- - -	- - -	0.0123
240	25.2	- - -	- - -	0.0246
360	37.8	0.069	5.42×10^{-6}	0.0368
480	50.5	- - -	- - -	0.0491
600	63.1	0.161	12.90 "	0.0614
720	75.6	0.011	0.90 "	0.0736
840	88.4	0.057	4.50 "	0.0860
960	101.0	0.034	2.68 "	0.0982
1080	113.6	0.069	5.42 "	0.1104
1200	126.1	0.126	9.95 "	0.1226
1320	138.9	0.252	19.90 "	0.1350
1440	151.2	0.355	28.00 "	0.1472
1560	164.0	0.458	36.20 "	0.1595
1680	176.6	0.653	51.55 "	0.1716
1800	189.0	0.734	57.90 "	0.1840

Material: Copper

Surface Finish: 4/0 paper

TABLE 1

1910-1911

1910-1911

1910-1911

1910-1911

1910-1911

Year	1910	1911	1912	1913	1914
1910	1.10	1.10	1.10	1.10	1.10
1911	1.10	1.10	1.10	1.10	1.10
1912	1.10	1.10	1.10	1.10	1.10
1913	1.10	1.10	1.10	1.10	1.10
1914	1.10	1.10	1.10	1.10	1.10
1915	1.10	1.10	1.10	1.10	1.10
1916	1.10	1.10	1.10	1.10	1.10
1917	1.10	1.10	1.10	1.10	1.10
1918	1.10	1.10	1.10	1.10	1.10
1919	1.10	1.10	1.10	1.10	1.10
1920	1.10	1.10	1.10	1.10	1.10
1921	1.10	1.10	1.10	1.10	1.10
1922	1.10	1.10	1.10	1.10	1.10
1923	1.10	1.10	1.10	1.10	1.10
1924	1.10	1.10	1.10	1.10	1.10
1925	1.10	1.10	1.10	1.10	1.10
1926	1.10	1.10	1.10	1.10	1.10
1927	1.10	1.10	1.10	1.10	1.10
1928	1.10	1.10	1.10	1.10	1.10
1929	1.10	1.10	1.10	1.10	1.10
1930	1.10	1.10	1.10	1.10	1.10

Material: Copper
Surface Finish: 40 Paper

SPECIMEN NO.15 (continued)

Run No.2 $F_N = 168.16 \text{ lb.}$ $F_N = 76.4 \text{ kg}$ $S_N = 11170 \text{ psi}$ $s_n = 785 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.011	0.90×10^{-6}	0.0294
360	0.023	1.81 "	0.0441
480	- - -	- - -	0.0588
600	0.011	0.90 "	0.0735
720	0.034	2.68 "	0.0882
840	0.034	2.68 "	0.1028
960	0.069	5.42 "	0.1175
1080	0.103	8.15 "	0.1320
1200	0.194	15.30 "	0.1470
1320	0.218	17.20 "	0.1615
1440	0.229	18.09 "	0.1762
1560	0.309	24.40 "	0.1910
1680	0.619	48.85 "	0.2060
1800	- - -	- - -	0.2203

Run No.3 $F_N = 117.41 \text{ lb.}$ $F_N = 53.3 \text{ kg}$ $S_N = 7800 \text{ psi}$ $s_n = 548 \text{ kg/cm}^2$

Q_A	ψ_R	θ_R	f
120	- - -	- - -	0.0211
240	- - -	- - -	0.0421
360	- - -	- - -	0.0632
480	0.023	1.81×10^{-6}	0.0842
600	0.126	9.95 "	0.1052
720	0.149	11.76 "	0.1265
840	0.229	18.09 "	0.1475
960	- - -	- - -	0.1686

λ	λ^2	λ^3	λ^4	λ^5	λ^6	λ^7	λ^8	λ^9	λ^{10}	λ^{11}	λ^{12}	λ^{13}	λ^{14}	λ^{15}	λ^{16}	λ^{17}	λ^{18}	λ^{19}	λ^{20}	
1000	1000000	1000000000	1000000000000	1000000000000000	1000000000000000000	1000000000000000000000	1000000000000000000000000	1000000000000000000000000000	10000000000000000000000000000000	10000000000000000000000000000000000	10000000000000000000000000000000000000	100	1000	100	100	100	100	100	1000	
1001	1002001	1006003001	1012006003001	1020012006003001	1030020012006003001	1042030020012006003001	1056042030020012006003001	1072056042030020012006003001	1089072056042030020012006003001	1108092072056042030020012006003001	1128116092072056042030020012006003001	1149244116092072056042030020012006003001	1171576144116092072056042030020012006003001	1195112176144116092072056042030020012006003001	1219852212176144116092072056042030020012006003001	1245796252212176144116092072056042030020012006003001	1272954296252212176144116092072056042030020012006003001	1301336344296252212176144116092072056042030020012006003001	1330952396344296252212176144116092072056042030020012006003001	1361812452396344296252212176144116092072056042030020012006003001
1002	1004004	1008008004	1016016008008004	1028028016008008004	1043043028008008004	1061061043008008004	1081081061008008004	1103103081008008004	1127127103008008004	1153153127008008004	1181181153008008004	1211211181008008004	1243243211008008004	1277277243008008004	1313313277008008004	1351351313008008004	1391391351008008004	1433433391008008004	1477477433008008004	1523523477008008004
1003	1006009	1012018009	1024036018009	1042054036018009	1066072054036018009	1096090072054036018009	1132108090072054036018009	1174126108090072054036018009	1222144126108090072054036018009	1276162144126108090072054036018009	1336180162144126108090072054036018009	1402198180162144126108090072054036018009	1474216198180162144126108090072054036018009	1552234216198180162144126108090072054036018009	1636252234216198180162144126108090072054036018009	1726270252234216198180162144126108090072054036018009	1822288270252234216198180162144126108090072054036018009	1924306288270252234216198180162144126108090072054036018009	2032324306288270252234216198180162144126108090072054036018009	
1004	1008016	1016032016	1032048032016	1056064048032016	1088080064048032016	1128096080064048032016	1176112096080064048032016	1232128112096080064048032016	1296144128112096080064048032016	1368160144128112096080064048032016	1448176160144128112096080064048032016	1536192176160144128112096080064048032016	1632208192176160144128112096080064048032016	1736224208192176160144128112096080064048032016	1848240224208192176160144128112096080064048032016	1968256240224208192176160144128112096080064048032016	2096272256240224208192176160144128112096080064048032016	2232288272256240224208192176160144128112096080064048032016	2376304288272256240224208192176160144128112096080064048032016	
1005	1010025	1020050025	1040075050025	1068100075050025	110412509007505002	114815010509007505002	119917513512509007505002	125719916515010509007505002	132222319517513512509007505002	139424722520016515010509007505002	147327125522519517513512509007505002	155929528525022520016515010509007505002	164231931527525522519517513512509007505002	173234334530028525022520016515010509007505002	182936737532531527525522519517513512509007505002	193339140535034525022520016515010509007505002	204441543537537527525522519517513512509007505002	216243946540040525022520016515010509007505002	228746349542543527525522519517513512509007505002	241948752545046525022520016515010509007505002
1006	1012036	1024072036	1048144072036	1076216096072036	1108288160096072036	1144360224120096072036	1184432288144120096072036	1228504352168144120096072036	1276576416192168144120096072036	1328648480216192168144120096072036	1384720544240216192168144120096072036	1444792608264240216192168144120096072036	1508864672288264240216192168144120096072036	1576936736312288264240216192168144120096072036	1649008800336312288264240216192168144120096072036	1725080864360336312288264240216192168144120096072036	1805152928384360336312288264240216192168144120096072036	1889224992408384360336312288264240216192168144120096072036	1977297056432408384360336312288264240216192168144120096072036	
1007	1014049	1028098049	1056236098049	1088374196098049	1124412294120098049	1164450392144120098049	1208488490168144120098049	1256526588192168144120098049	1308564686216192168144120098049	1364602784240216192168144120098049	1424640882264240216192168144120098049	1488678980288264240216192168144120098049	1556717078312288264240216192168144120098049	1628755176336312288264240216192168144120098049	1704793274360336312288264240216192168144120098049	1784831372384360336312288264240216192168144120098049	1868869470408384360336312288264240216192168144120098049	1956907568432408384360336312288264240216192168144120098049	2048945666456432408384360336312288264240216192168144120098049	
1008	1016064	1032115264	1064353315264	1096591466664	113272961866664	1174967770666664	12212059226666664	127144407466666664	1325682226666666664	13839203786666666664	144615853066666666664	1512396682666666666664	15826348346666666666664	165687298666666666666664	1735111138666666666666664	18173492906666666666666664	190258744266666666666666664	1990825594666666666666666664	20820637466666666666666666664	
1009	1018081	1036136881	1072594936881	1109056098881	1149517260881	1193978422881	1242439584881	1294899746881	1351359908881	1411820070881	1476280232881	1544740394881	1617200556881	1693660718881	1774120880881	1858581042881	1947041204881	2039501366881	2135961528881	
1010	1020100	1040200100	1060400200100	10806003003000	11008004005000	11210005007000	11412006009000	11614007011000	11816008013000	12018009015000	12220010017000	12422011019000	12624012021000	12826013023000	13028014025000	13230015027000	13432016029000	13634017031000	13836018033000	14038019035000
1011	1022121	1044242221	1066484342221	1088746464442	1111028586664	1133330708886	1155652831108	1177994953330	1200357075552	1222739197774	1245141319996	1267563442218	1289995564440	1312437686662	1334889808884	1357351931106	1379824053328	1402306175550	1424798297772	1447300419994
1012	1024144	1048288644	1072553768644	1096839892888	1121147017132	1145475141376	1169824265620	1194194389864	1218585514108	1242997638352	1267430762596	1291884886840	1316359011084	1340853135328	1365367259572	1389891383816	1414425508060	1438969632304	1463533756548	1488117880792
1013	1026169	1050338169	1074632293169	1098942417413	1123268541657	1147610665901	1171968790145	1196342914389	1220733038633	1245139162877	1269561287121	1293999411365	1318453535609	1342923659853	1367409784097	1391911908341	1416430032585	1440964156829	1465514281073	1490080405317
1014	1028196	1052472476	1076946601476	1101440725720	1125954850064	1150489974308	1175046098552	1199623222796	1224221347040	1248840471284	1273480595528	1298141719772	1322823844016	1347526968260	1372251092504	1396996216748	1421762340992	1446549465236	1471357589480	1496186713724
1015	1030225	1054665025	1079199150025	1103764274269	1128599398513	1153454522757	1178330647001	1203227771245	1228145895489	1253085019733	1278045143977	1303026268221	1328028392465	1353051516709	1378095640953	1403160765197	1428246889441	1453354013685	1478482137929	1503631262173
1016	1032256	1056712416	1081346541416	1106679665660	1131434790004	1156205914248	1180993038492	1205796162736	1230615286980	1255450411224	1280301535468	1305168659712	1330051783956	1354950908200	1379876032444	1404827156688	1429804280932	1454807405176	1479836529420	1504891653664
1017	1034289	1058756881	1083490910881	1108004035125	1132759160369	1157534284613	1182330408857	1207147533101	1231985657345	1256844781589	1281724905833	1306626030077	1331548154321	1356491278565	1381455402809	1406440527053	1431446651297	1456473775541	1481521899785	1506591024029
1018	1036324	1060797676	1085631701676	1110248859380	1135024984624	1159822108868	1184640233112	1209479357356	1234339481600	1259220605844	1284122730088	1309045854332	1333989978576	1358955102820	1383941227064	1408948351308	1433976475552	1459025599796	1484095724040	1509186848284
1019	1038361	1062817641	1087651676641	1112498063125	1137284188369	1162092312613	1186922436857	1211774561101	1236648685345	1261544809589	1286462933833	1311403058077	1336365182321	1361349306565	1386355430809	1411383555053	1436433679297	1461505803541	1486599927785	1511716052029
1020	1040400	1064872000	1089764000000	1114100000000	1138992000000	1163900000000	1188824000000	1213764000000	1238720000000	1263692000000	1288680000000	1313684000000	1338704000000	1363740000000	1388792000000	1413860000000	1438944000000	1464044000000	1489160000000	1514292000000
1021	1042441	1066915241	1091817241041	1116199241285	1141101241529	1166025241773	1190971242017	1215939242261	1240929242505	1265941242749	1290975242993	1316031243237	1341109243481	1366209243725	1391331243969	1416475244213	1441641244457	1466829244701	1492039244945	1517271245189
1022	1044484	1068958484	1093869484084	1118100484328	1143002484572	1167926484816	1192872485060	1217840485304	1242830485548	1267842485792	1292876486036	1317932486280	1343010486524	1368110486768	1393232487012	1418376487256	1443542487500	1468730487744	1493940487988	1519172488232
1023	1046529	1070999649	1095910649089	1120091649273	1144993649517	1169917649761	1194863650005	1219831650249	1244821650493	1269833650737	1294867650981	1319923651225	1345001651469	1370101651713	1395223651957	1420367652201	1445533652445	1470721652689	1495931652933	1521163653177
1024	1048576	1073046416	1097957416096	1122084016367	1146986016611	1171900016855	1196826017100	1221774017344	1246744017588	1271736017832	1296750018076	1321786018320	1346844018564	1371924018808	1397026019052	1422150019296	1447296019540	1472464019784	1497654020028	152

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SPECIMEN NO.15 (continued)

Run No.4

$$F_N = 168.16 \text{ lb.}$$

$$F_N = 76.4 \text{ kg}$$

$$S_N = 11170 \text{ psi}$$

$$s_n = 785 \text{ kg/cm}^2$$

C_A	ϕ_R	θ_R	f
120	- - -	- - -	0.0147
240	0.103	8.15×10^{-6}	0.0294
360	0.149	11.76 "	0.0441
480	0.195	15.40 "	0.0588
600	0.344	27.15 "	0.0735
720	0.413	32.60 "	0.0882
840	0.768	60.65 "	0.1028
960	1.134	89.50 "	0.1175
1080	- - -	- - -	0.1320

3	3 ⁰	3 ¹	3 ²
7220.0	- - -	- - -	021
2980.0	28 25.9	101.0	022
1340.0	8 87.11	941.0	023
3070.0	7 14.31	441.0	024
1170.0	7 11.73	141.0	025
1480.0	8 06.11	711.0	026
3901.0	9 28.04	871.0	027
1911.0	7 04.08	171.1	028
0871.0	- - -	- - -	029

SPECIMEN NO.15 (continued)

Run No.5

$P_N = 117.41 \text{ lb.}$
 $P_N = 53.3 \text{ kg}$
 $S_N = 7800 \text{ psi}$
 $s_n = 548 \text{ kg/cm}^2$

Q_A	ϕ_R	θ_R	f
120	0.080	6.34×10^{-6}	0.0211
240	0.321	25.30	0.0421
360	0.596	47.10	0.0632
480	1.396	110.0	0.0842
600	- - -	- - -	0.1052

Run No.7

$P_N = 64.78 \text{ lb.}$
 $P_N = 29.4 \text{ kg}$
 $S_N = 4300 \text{ psi}$
 $s_n = 302 \text{ kg/cm}^2$

ϕ_R	θ_R	f
0.092	7.24×10^{-6}	0.0382
0.241	19.04	0.0763
0.940	74.20	0.1144
8.50	671.0	0.1526

(continued) 21-22

21-22

$$\text{all } 21-22 = 2^2$$

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SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.1

$$F_N = 764 \text{ kg}$$

$$s_n = 772 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f	ψ_o
12	1.24	0.458	30.10×10^{-6}	0.0015	0.183
30	3.11	0.138	10.87 "	0.0037	0.413
60	6.23	0.138	10.87 "	0.0073	0.836
90	9.33	0.275	21.65 "	0.0119	1.064
120	12.43	0.321	25.30 "	0.0147	1.443
150	15.55	0.424	33.40 "	0.0183	1.866
180	18.65	0.596	47.00 "	0.0220	2.085
210	21.80	0.699	55.10 "	0.0256	2.462
240	24.90	0.630	49.65 "	0.0293	2.820
270	28.00	0.722	57.00 "	0.0330	3.130
300	31.15	0.756	59.60 "	0.0367	3.450
330	34.25	0.814	64.15 "	0.0403	3.930
360	37.35	0.836	65.95 "	0.0440	4.220
390	40.50	0.956	75.40 "	0.0476	4.530
420	43.65	0.985	77.60 "	0.0514	4.810

SPECIMEN NO.16 (continued)

Material: 2S Aluminum

Surface Finish: No. 1 Paper

Run No.2

$$F_N = 91.3 \text{ kg}$$

$$s_n = 928 \text{ kg/cm}^2$$

Q_A	s_t	ψ_R	θ_R	f	ψ_o
12	1.24	- - -	- - -	0.0012	- - -
30	3.11	- - -	- - -	0.0031	0.378
60	6.23	- - -	- - -	0.0061	0.596
90	9.33	0.114	9.00×10^{-6}	0.0092	1.030
120	12.43	0.138	10.87 "	0.0123	1.283
150	15.55	0.183	14.42 "	0.0153	1.640
180	18.65	0.138	10.87 "	0.0184	1.970
210	21.80	0.206	16.24 "	0.0214	2.220
240	24.90	0.252	19.86 "	0.0245	2.625
270	28.00	0.283	22.30 "	0.0276	2.980
300	31.15	0.367	28.90 "	0.0307	3.240
330	34.25				

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n°	z	z^0	x^y	y^x	A^2
- - -	5130.0	- - -	- - -	12.5	21
871.0	1000.0	- - -	- - -	12.1	00
071.0	1000.0	- - -	- - -	12.0	00
000.0	5000.0	01 x 00.0	111.0	12.8	07
011.1	0100.0	" 78.00	010.0	12.1	041
010.1	0100.0	" 11.11	011.0	12.1	021
070.1	1010.0	" 78.01	010.0	12.0	001
010.0	1100.0	" 11.10	010.0	08.10	010
000.0	0100.0	" 00.00	010.0	08.10	010
000.0	0000.0	" 00.00	000.0	00.00	000
000.0	0000.0	" 00.00	000.0	00.00	000

APPENDIX C
SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

Calculated angle of twist of specimen without interface = ψ_o

$$\psi = \frac{T_A L}{E_s J} \text{ radians} \quad (1)$$

$$J = \frac{\pi(D_o^4 - D_i^4)}{32} \quad (2)$$

$$\psi_c = \frac{180}{\pi} \times 60 \times \psi \quad (3)$$

$$T_A = 2.205 \times 10^{-3} Q_A \quad (4)$$

Substituting (2), (3), and (4) in (1) gives

$$\psi_c = \frac{77.3 \times Q_A \times L}{(D_o^4 - D_i^4) \times E_s} \text{ Min.arc.} \quad (5)$$

Maximum tangential stress = S_T .

$$S_T = \frac{16 T_A D_o}{\pi(D_o^4 - D_i^4)} \quad (6)$$

Substituting (4) in (6) gives

$$S_T = 1.121 \times 10^{-2} \frac{D_o}{D_o^4 - D_i^4} \times Q \text{ psi} \quad (7)$$

Observed angle of twist of specimen = ψ_o .

With 10 x objective calibration with micrometer stage shows one drum unit of optical micrometer represents 0.00004101" on indicator.

EXPERIMENTAL

Calculated value of rate of reaction with

$$\text{interior} = \frac{1}{2}$$

$$(2) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

$$(3) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

$$(4) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

$$(5) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Interpolating (2), (3), and (4) to give

$$(6) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Calculated value of rate of reaction with

$$(7) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Interpolating (6) to give

$$(8) \quad \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

Calculated value of rate of reaction with

With a constant rate of reaction with

above can be used to predict the rate of

reaction with

ψ_s drum units = 0.00004101 x ψ_s inches on indicator.

$$\psi_o = \frac{\psi_s}{R} \text{ radians} \times \frac{180}{\pi} \frac{\text{degrees}}{\text{radians}} \times 60 \frac{\text{min.}}{\text{degree}} .$$

$$\psi_o = \frac{\psi_s (0.00004101)}{12.33} \times 3440$$

$$\psi_o = 0.01144 \psi_s \quad (8)$$

Coefficient of friction = f .

$$T = \frac{1}{3} f \times F_N \frac{(D_o^3 - D_1^3)}{(D_o^2 - D_1^2)} \quad (9)$$

T = torque of friction about axis of shaft.

Substituting (4) in (9) gives

$$f = \frac{Q_A}{F_N} \times 6.615 \times 10^{-3} \times \frac{(D_o^2 - D_1^2)}{(D_o^3 - D_1^3)}$$

4. Given ratio = 0.000001 = 1/1000000 = 1/10^6

$$\frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

$$\frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

$$(10) \quad \frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

Coefficient of friction = 1/1000

$$(11) \quad \frac{1}{10^6} = \frac{1}{10^3} \times \frac{1}{10^3} = \frac{1}{1000} \times \frac{1}{1000}$$

1/1000 = Coefficient of friction about axis of wheel.

Substituting (11) in (9) gives

$$\frac{(1/10^3 - 1/10^3)}{(1/10^3 - 1/10^3)} = \frac{1/10^3 - 1/10^3}{1/10^3 - 1/10^3} = 1$$

APPENDIX D
SUPPLEMENTARY DISCUSSION

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SUPPLEMENTARY DISCUSSION

In the discussion of results, it was suggested that yield effects in the metal of the interfaces contributed to the small initial deformations. An examination of one of the test runs for this effect is therefore in order.

Referring to Figure XIV, let us examine the stress situation in the C-1018 steel specimen for one of the initial deformations.

The maximum combined shearing stress in a cylinder loaded in this manner is given as follows: $(S_s)_{\max} = \sqrt{\frac{1}{4}(S_N)^2 + (S_T)^2}$
For S_N and S_T values, respectively, of 13200 and 1420 psi, the $(S_s)_{\max}$ is equal to 6750 psi.

Maximum shear theory states that yielding will occur when $(S_s)_{\max}$ equals the maximum shearing stress at yield point obtained from a tension test. The maximum shearing stress at yield point is one half yield stress for a tensile specimen.

Ryerson Steel Specifications for C-1018 steel give a yield value of 48000 psi.

Therefore maximum shear stress at yield point equals 24000 psi. The calculated stress for the specimen is well below this value; therefore yield will not occur in the bulk metal.

The normal stress value used in computing the combined shear stress was determined by using the cross-section area of the specimen, which at the interface is the apparent area of

contact. The real area of contact is less than this value due to the asperities in the metal of the interface.

Bowden and Tabor⁽⁴⁾ give the following relation for real area of contact:

$$A_r = \frac{F}{P_m}$$

P_m = mean pressure over area of contact

$$P_m = C \times S_{\text{yield}}$$

C has a value of 3 for material and surface finish used here.

$$P_m = 144000 \text{ psi for this case.}$$

$$A_{\text{real}} = 0.0014 \text{ in}^2, \text{ which is considerably less than the apparent value of } 0.0153 \text{ in}^2.$$

This would give a maximum combined shear stress in the contact surface considerably in excess of that required to initiate yield in the metal.

It is thus apparent that the stresses at the contact surface are more than sufficient to insure yield in the asperities in the metal interface. For very small values of deformation, the yield effects may thus be the sole contributing factor.

Now consider the stress values for the specimen under conditions encountered just prior to the advent of free sliding to S_N and S_T of 13200 and 4960 psi. The $(S_s)_{\text{max}}$ value is 8260 psi. Thus it is apparent that yield in the bulk material of the specimen does not occur, and all but the smallest displacements are due to slip between the two contact surfaces.

constant. The steel wire of constant is less than this value
due to the expansion in the metal of the interface.

From the above (4) gives the following relation for steel

and of constant for steel is the following relation for steel

$$\frac{1}{2} \frac{d}{d} = \frac{1}{2} \frac{d}{d} \quad (5)$$

From the above (4) gives the following relation for steel

$$\frac{1}{2} \frac{d}{d} = \frac{1}{2} \frac{d}{d} \quad (6)$$

From the above (4) gives the following relation for steel

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From the above (4) gives the following relation for steel

APPENDIX E
ORIGINAL DATA

SPECIMEN NO.1

Material: C-1018 Steel

Control Specimen (without interface)

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
	$F_N = 150 \text{ lb.}$	$F_N = 190.7 \text{ lb.}$	$F_N = 225.4 \text{ lb.}$	$F_N = 74.9 \text{ lb.}$	$F_N = 111.9 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s
150	44	44	49	40	45
300	92	89	96	101	97
450	139	143	146	-	144
600	189	197	193	-	196
750	239	243	-	-	-
900	285	296	292	-	-
1050	332	-	342	-	-
1200	-	-	391	-	-
1350	-	-	-	-	-

SPECIMEN NO.2

Material: C-1018 Steel

Surface Finish:
As machined (lathe)Run No.1 $F_N = 251.2 \text{ lb.}$

Q_A	ψ_S
120	31
240	60
360	103
480	145
600	187
720	227
840	266
900	282
960	300
1080	342
1200	384
1320	433
1440	478

SPECIMEN NO.3

Material: C-1018 Steel

Surface Finish: No.1 Paper

Run No.2 $F_N = 200.3 \text{ lb.}$

Q_A	ψ_S
120	38
240	80
360	123
480	168
600	203
720	241
840	-
900	-

Run No.3 $F_N = 201.29 \text{ lb.}$

Q_A	ψ_S	Q_A	ψ_{SR}	ψ_{SR}
120	36	120	--	30
240	74	240	--	40
360	110	360	--	50
480	144	480	--	56
600	183.5	600	--	70
720	226	720	5	82
840	268	840	7	97
900	-	900	--	124
		960	17	125
		1080	16	156
		1200	18	254
		1320	20	257
		1440	28	270
		1560	30	319
		1680	31	--

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SPECIMEN NO.3 (continued)

<u>Run No.3 (cont.)</u>		<u>Run No.4</u>		<u>Run No.5</u>		<u>Run No.6</u>	
$F_N = 201.29 \text{ lb.}$		$F_N = 168.16 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
Q_A	ψ_{SR}	Q_A	ψ_{SR}	Q_A	ψ_{SR}	Q_A	ψ_{SR}
2520	97	120	--	120	--	120	--
2640	124	240	--	240	15	240	--
2760	125	360	--	360	16	360	5
2880	156	480	--	480	13	480	16
3000	254	600	--	600	24	600	19
3120	257	720	2	720	19	720	317
3240	270	840	5	840	28	840	--
3360	319	960	8	960	29		
3480	--	1080	7	1080	29		
		1200	7	1200	41		
		1320	30	1320	58		
		1440	30	1440	75		
		1560	28	1560	109		
		1680	41	1680	--		
		1800	58				
		1920	67				
		2040	78				
		2160	142				
		2280	214				
		2400	--				

Chemical Equations

Reaction

Equation

Heat

(-7000) Heat

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

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at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

at 25°C, $\Delta H = 0$ kcal/mol

SPECIMEN NO.4

Material: C-1018 Steel

Surface Finish: 2/o Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>	<u>Run No.6</u>
	$F_N = 81.75 \text{ lb.}$	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 200.3 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s	ψ_s
120	54	34	39	46	32	33
240	115	83	72	71	68	75
300	--	--	--	83	--	--
360		114	108	--	105	107
420	--	--	--	114	--	--
480			146	--	145	149
600			192	182	180	186
720			231	220	218	226
840			279	--	258	266
900			--	273	--	--
960				--	294	308
1020				320	--	--
1080				--	336	349
1140				372	--	--
1200				--	373	379
1320					413	416
1440					--	--

DATA SUMMARY

DATA SOURCE: Literature

DATA TYPE: Quantitative

Base unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2 Fuel unit: g^2

00	00	00	00	00	00
01	01	01	01	01	01
02	02	02	02	02	02
03	03	03	03	03	03
04	04	04	04	04	04
05	05	05	05	05	05
06	06	06	06	06	06
07	07	07	07	07	07
08	08	08	08	08	08
09	09	09	09	09	09
10	10	10	10	10	10
11	11	11	11	11	11
12	12	12	12	12	12
13	13	13	13	13	13
14	14	14	14	14	14
15	15	15	15	15	15
16	16	16	16	16	16
17	17	17	17	17	17
18	18	18	18	18	18
19	19	19	19	19	19
20	20	20	20	20	20
21	21	21	21	21	21
22	22	22	22	22	22
23	23	23	23	23	23
24	24	24	24	24	24
25	25	25	25	25	25
26	26	26	26	26	26
27	27	27	27	27	27
28	28	28	28	28	28
29	29	29	29	29	29
30	30	30	30	30	30
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33	33	33	33	33	33
34	34	34	34	34	34
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36	36	36	36	36	36
37	37	37	37	37	37
38	38	38	38	38	38
39	39	39	39	39	39
40	40	40	40	40	40
41	41	41	41	41	41
42	42	42	42	42	42
43	43	43	43	43	43
44	44	44	44	44	44
45	45	45	45	45	45
46	46	46	46	46	46
47	47	47	47	47	47
48	48	48	48	48	48
49	49	49	49	49	49
50	50	50	50	50	50
51	51	51	51	51	51
52	52	52	52	52	52
53	53	53	53	53	53
54	54	54	54	54	54
55	55	55	55	55	55
56	56	56	56	56	56
57	57	57	57	57	57
58	58	58	58	58	58
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66	66	66	66	66	66
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69	69	69	69	69	69
70	70	70	70	70	70
71	71	71	71	71	71
72	72	72	72	72	72
73	73	73	73	73	73
74	74	74	74	74	74
75	75	75	75	75	75
76	76	76	76	76	76
77	77	77	77	77	77
78	78	78	78	78	78
79	79	79	79	79	79
80	80	80	80	80	80
81	81	81	81	81	81
82	82	82	82	82	82
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87	87	87	87	87	87
88	88	88	88	88	88
89	89	89	89	89	89
90	90	90	90	90	90
91	91	91	91	91	91
92	92	92	92	92	92
93	93	93	93	93	93
94	94	94	94	94	94
95	95	95	95	95	95
96	96	96	96	96	96
97	97	97	97	97	97
98	98	98	98	98	98
99	99	99	99	99	99
100	100	100	100	100	100

SPECIMEN NO.5

Material: C-1018 Steel

Surface Finish: 4/o paper

<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>		<u>Run No.4</u>	
$F_N = 116.3 \text{ lb.}$		$F_N = 167 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$		$F_N = 251.2 \text{ lb.}$	
Q_A	ψ_s	Q_A	ψ_s	Q_A	ψ_s	Q_A	ψ_s
120	33	120	39	120	30	120	--
150	--	150	--	150	--	150	43
240	73	240	82	240	74	240	--
300	--	300	--	300	--	300	91
360	108	360	126	360	117	360	--
420	--	420	--	420	--	420	--
450	--	450	--	450	--	450	141
480	153	480	167	480	151	480	--
600	188	600	201	600	191	600	190
720	228	720	232	720	230	720	--
750	--	750	--	750	--	750	241
840	318	840	280	840	269	840	--
900	--	900	--	900	--	900	291
960	--	960	321	960	310	960	--
		1020	--	1020	--	1020	--
		1050	--	1050	--	1050	332
		1080	385	1080	351	1080	--
		1140	--	1140	--	1140	--
				1200	390	1200	393
				1320	430	1320	--
				1350	--	1350	438
						1440	--
						1500	492
						1560	--

1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2423	2424	2425	2426	2427	2428	2429	2430	2431	2432	2433	2434	2435	2436	2437	2438	2439	2440	2441	2442	2443	2444	2445	2446	2447	2448	2449	2450	2451	2452	2453	2454	2455	2456	2457	2458	2459	2460	2461	2462	2463	2464	2465	2466	2467	2468	2469	2470	2471	2472	2473	2474	2475	2476	2477	2478	2479	2480	2481	2482	2483	2484	2485	2486	2487	2488	2489	2490	2491	2492	2493	2494	2495	2496	2497	2498	2499	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514	2515	2516	2517	2518	2519	2520	2521	2522	2523	2524	2525	2526	2527	2528	2529	2530	2531	2532	2533	2534	2535	2536	2537	2538	2539	2540	2541	2542	2543	2544	2545	2546	2547	2548	2549	2550	2551	2552	2553	2554	2555	2556	2557	2558	2559	2560	2561	2562	2563	2564	2565	2566	2567	2568	2569	2570	2571	2572	2573	2574	2575	2576	2577	2578	2579	2580	2581	2582	2583	2584	2585	2586	2587	2588	2589	2590	2591	2592	2593	2594	2595	2596	2597	2598	2599	2600	2601	2602	2603	2604	2605	2606	2607	2608	2609	2610	2611	2612	2613	2614	2615	2616	2617	2618	2619	2620	2621	2622	2623	2624	2625	2626	2627	2628	2629	2630	2631	2632	2633	2634	2635	2636	2637	2638	2639	2640	2641	2642	2643	2644	2645	2646	2647	2648	2649	2650	2651	2652	2653	2654	2655	2656	2657	2658	2659	2660	2661	2662	2663	2664	2665	2666	2667	2668	2669	2670	2671	2672	2673	2674	2675	2676	2677	2678	2679	2680	2681	2682	2683	2684	2685	2686	2687	2688	2689	2690	2691	2692	2693	2694	2695	2696	2697	2698	2699	2700	2701	2702	2703	2704	2705	2706	2707	2708	2709	2710	2711	2712	2713	2714	2715	2716	2717	2718	2719	2720	2721	2722	2723	2724	2725	2726	2727	2728	2729	2730	2731	2732	2733	2734	2735	2736	2737	2738	2739	2740	2741	2742	2743	2744	2745	2746	2747	2748	2749	2750	2751	2752	2753	2754	2755	2756	2757	2758	2759	2760	2761	2762	2763	2764	2765	2766	2767	2768	2769	2770	2771	2772	2773	2774	2775	2776	2777	2778	2779	2780	2781	2782	2783	2784	2785	2786	2787	2788	2789	2790	2791	2792	2793	2794	2795	2796	2797	2798	2799	2800	2801	2802	2803	2804	2805	2806	2807	2808	2809	2810	2811	2812	2813	2814	2815	2816	2817	2818	2819	2820	2821	2822	2823	2824	2825	2826	2827	2828	2829	2830	2831	2832	2833	2834	2835	2836	2837	2838	2839	2840	2841	2842	2843	2844	2845	2846	2847	2848	2849	2850	2851	2852	2853	2854	2855	2856	2857	2858	2859	2860	2861	2862	2863	2864	2865	2866	2867	2868	2869	2870	2871	2872	2873	2874	2875	2876	2877	2878	2879	2880	2881	2882	2883	2884	2885	2886	2887	2888	2889	2890	2891	2892	2893	2894	2895	2896	2897	2898	2899	2900	2901	2902	2903	2904	2905	2906	2907	2908	2909	2910	2911	2912	2913	2914	2915	2916	2917	2918	2919	2920	2921	2922	2923	2924	2925	2926	2927	2928	2929	2930	2931	2932	2933	2934	2935	2936	2937	2938	2939	2940	2941	2942	2943	2944	2945	2946	2947	2948	2949	2950	2951	2952	2953	2954	2955	2956	2957	2958	2959	2960	2961	2962	2963	2964	2965	2966	2967	2968	2969	2970	2971	2972	2973	2974	2975	2976	2977	2978	2979	2980	2981	2982	2983	2984	2985	2986	2987	2988	2989	2990	2991	2992	2993	2994	2995	2996	2997	2998	2999	3000	3001	3002	3003	3004	3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3019	3020	3021	3022	3023	3024	3025	3026	3027	3028	3029	3030	3031	3032	3033	3034	3035	3036	3037	3038	3039	3040	3041	3042	3043	3044	3045	3046	3047	3048	3049	3050	3051	3052	3053	3054	3055	3056	3057	3058	3059	3060	3061	3062	3063	3064	3065	3066	3067	3068	3069	3070	3071	3072	3073	3074	3075	3076	3077	3078	3079	3080	3081	3082	3083	3084	3085	3086	3087	3088	3089	3090	3091	3092	3093	3094	3095	3096	3097	3098	3099	3100	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150	3151	3152	3153	3154	3155	3156	3157	3158	3159	3160	3161	3162	3163	3164	3165	3166	3167	3168	3169	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180	3181	3182	3183	3184	3185	3186	3187	3188	3189	3190	3191	3192	3193	3194	3195	3196	3197	3198	3199	3200	3201	3202	3203	3204	3205	3206	3207	3208	3209	3210	3211	3212	3213	3214	3215	3216	3217	3218	3219	3220	3221	3222	3223	3224	3225	3226	3227	3228	3229	3230	3231	3232	3233	3234	3235	3236	3237	3238	3239	3240	3241	3242	3243	3244	3245	3246	3247	3248	3249	3250	3251	3252	3253	3254	3255	3256	3257	3258	3259	3260	3261	3262	3263	3264	3265	3266	3267	3268	3269	3270	3271	3272	3273	3274	327
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SPECIMEN NO.5 (continued)

<u>Run No.5</u>		<u>Run No.6</u>		<u>Run No.7</u>	
$F_N = 168.2 \text{ lb.}$		$F_N = 117.41 \text{ lb.}$		$F_N = 64.78 \text{ lb.}$	
Q_A	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}	
120	--	--	--	--	
150	--	--	--	--	
240	--	--	--	16	
300	--	--	--	--	
360	--	3	--	16	
420	--	--	--	--	
450	--	--	--	--	
480	--	4	--	36	
600	--	19	--	64	
720	--	16	--	67	
750	--	--	--	--	
840	--	32	--	153	
900	--	--	--	--	
960	6	40	--	--	
1020	--	--	--	--	
1050	--	--	--	--	
1080	6	68	--	--	
1140	--	--	--	--	
1200	10	94	--	--	
1320	15	122	--	--	
1350	--	--	--	--	
1440	19	155	--	--	
1500	--	--	--	--	
1560	23	--	--	--	
1680	39	--	--	--	
1800	64	--	--	--	

5.04-015

100 = 100.00 % 100 = 100.00 % 100 = 100.00 %

SPECIMEN NO.6

Material: A-4140 Steel

Control Specimen (without interface)

<u>Run No.1</u>		<u>Run No.2</u>
$F_N = 251.2 \text{ lb.}$		$F_N = 200.2 \text{ lb.}$
Q_A	ψ_s	ψ_s
120	43	--
150	--	52
240	83	--
300	--	93
360	123	--
450	--	139
480	161	--
600	202	192
720	245	--
750	--	239
840	290	--
900	--	290
960	326	--
1020	--	
1080	363	
1200	400	

SECTION 3016

Material: A-110 Steel

(continued from page 3015)

See Table

See Table

at 2.005 in.

at 2.113 in.

1/2

1/2

1/2

—

43

110

25

—

130

—

83

140

88

—

150

—

153

160

132

—

170

—

181

180

103

200

190

—

248

220

138

—

230

—

280

240

160

—

250

—

350

260

—

270

363

280

400

290

SPECIMEN NO. 7

Material: A-4140 Steel

Surface Finish: As machined

	<u>Run No. 1</u>	<u>Run No. 2</u>	<u>Run No. 3</u>	<u>Run No. 4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s
120	32	38	38	42
150	--	--	--	51
240	74	78	--	--
300	--	--	108	119
360	123	130	--	--
450	--	--	--	--
480	169	187	--	--
600	219	236	214	211
720	--	294	270	--
750	--	--	--	--
840	--	--	--	--
900	--	--	356	344
960	--	--	--	--
1020				397

SPECIMEN NO.8

Material: A-4140 Steel

Surface Finish: No.1 Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>
	$F_N = 116.3 \text{ lb.}$	$F_N = 167 \text{ lb.}$	$F_N = 200.2 \text{ lb.}$	$F_N = 251.2 \text{ lb.}$
Q_A	ψ_s	ψ_s	ψ_s	ψ_s
150	54	59	48	51
300	111	116	109	109
450	165	168	178	161
600	241	223	220	219
750	284	277	276	287
900	--	--	339	340
1050			--	393

9.07 EMISSIONS

Check only - 11/11/67
 report 1.00 - identify location

2000.000 2000.000 2000.000 2000.000
 at 2.500 $\times 10^4$ at 2.500 $\times 10^4$ at 2.500 $\times 10^4$ at 2.500 $\times 10^4$

λ^0	λ^0	λ^0	λ^0	λ^0
22	71	92	92	021
401	701	211	111	007
111	871	851	201	025
824	845	828	145	001
785	873	775	165	077
034	870	—	—	004
797	—	—	—	000

SPECIMEN NO.8 (continued)

Run No.5

Run No.6

Run No.7

$F_N = 200 \text{ lb.}$

$F_N = 167 \text{ lb.}$

$F_N = 201.29 \text{ lb.}$

Q_A	ψ_s	ψ_s	Q_A	ψ_s
150	59	49	120	--
300	111	122	240	--
450	160	186	360	--
600	220	219	480	--
750	--	280	600	--
900		--	720	--
			840	--
			960	1
			1080	4
			1200	5
			1320	8
			1440	8
			1560	12
			1680	22
			1800	36
			1920	70
			2040	75
			2160	132
			2280	232
			2400	--

[illegible]

SPECIMEN NO.8 (continued)

Run No.8Run No.9Run No.10 $F_N = 168.16 \text{ lb.}$ $F_N = 117.41 \text{ lb.}$ $F_N = 64.78 \text{ lb.}$

Q_A	ψ_{sR}	ψ_{sR}	ψ_{sR}
120	--	--	--
240	--	--	15
360	--	12	73
480	--	22	772
600	10	57	--
720	35	91	
840	42	159	
960	79	283	
1080	85	--	
1200	82		
1320	99		
1440	115		
1560	135		
1680	209		
1800	225		
1920	239		
2040	266		
2160	475		
2280	--		

SPECIMEN NO.10

Material: 2S Aluminum

Control Specimen: without interface

Q _A	Run No.1			Run No.2			Run No.3		
	F _N = 116 lb.			F _N = 16 lb.			F _N = 200 lb.		
	ψ_s	ψ_{SR}		ψ_s	ψ_s		ψ_s	ψ_s	
30	28	--		22	6		--	--	
60	60	--		50	5		53	7	
90	96	19		--	--		--	--	
120	119	19		100	4		101	1	
150	152	30		--	--		--	--	
180	181	26		135	21		--	--	
210	211	32		--	--		--	--	
240	250	39		221	30		229	29	
270	271	40		--	--		--	--	
300	296	42		272	31		274	29	
330	323	35		--	--		--	--	
360	360	44		336	35		337	46	
420	--	--		393	53		--	--	

SPECIMEN NO.11

Material: Copper

Control Specimen
(without interface)

<u>Run No.1</u>			<u>Run No.2</u>		<u>Run No.3</u>	
$F_N = 20 \text{ lb.}$			$F_N = 250 \text{ lb.}$		$F_N = 200 \text{ lb.}$	
Q_A	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	Q_A	ψ_{sR}
30	29	--	24	4	120	--
60	48	4	--	--	240	5
90	68	14	61	7	360	5
120	85	4	--	--	480	8
150	92	6	100	4	600	10
180	117	14	--	--	720	19
210	138	28	137	--	840	28
240	154	22	--	--	960	27
270	173	28	170	15	1080	25
300	191	37	--	--	1200	40
330	211	35	205	18	1320	50
360	228	37	--	--	1440	58
390	248	44	236	22	1560	71
420	261	48	--	--	1680	87
450	281	56	--	--	1800	84

SPECIMEN NO.12

Material: A-4140 Steel

Surface Finish: 4/0 Paper

	<u>Run No.1</u>			<u>Run No.2</u>			<u>Run No.3</u>			<u>Run No.4</u>		
	$F_N = 31.875 \text{ lb.}$			$F_N = 53.38 \text{ lb.}$			$F_N = 117.41 \text{ lb.}$			$F_N = 168.2 \text{ lb.}$		
Q_A	ψ_S	ψ_{SR}		ψ_S	ψ_{SR}		ψ_S	ψ_{SR}		ψ_S	ψ_{SR}	
120	54	--		59	10		45	--		--	--	
150	--	--		--	--		53	--		58	--	
240	94	4		116	16		100	--		--	--	
300	--	--		--	--		122	--		105	--	
360	156	13		176	28		142	1		--	--	
450	--	--		--	--		180	--		164	--	
480	277	72		265	75		186	4		--	--	
600	--	--		365	225		228	16		231	14	
720				562	269		265	58		--	--	
750				--	--		270	--		283	10	
840							295	60		--	--	
960							345	76				
1080								92				
1200								100				
1320								149				
1440								183				
1560								267				
1680								659				

SPECIMEN NO.12 (continued)

	<u>Run No. 5</u>		<u>Run No. 6</u>		<u>Run No. 7</u>		<u>Run No. 8</u>	
	$F_N = 168.2 \text{ lb.}$		$F_N = 201.3 \text{ lb.}$		$F_N = 201.3 \text{ lb.}$		$F_N = 250 \text{ lb.}$	
Q_A	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}
150	54	--	60	--	59	--	69	--
300	113	--	119	--	113	--	123	--
450	162	--	178	--	174	--	174	--
600	225	8	237	3	236	--	238	--
750	273	14	302	17	303	12	294	12
900	387	172	371	23	350	12	351	12
1050	--	--	446	30	--	22	423	22

(continued) EL-08 8/28/2018

Sub. no.	Sub. no.	Sub. no.	Sub. no.	Sub. no.
at dec = 0°	at lat = 0°	at lat = 0°	at lat = 0°	at lat = 0°
1001	1001	1001	1001	1001
1002	1002	1002	1002	1002
1003	1003	1003	1003	1003
1004	1004	1004	1004	1004
1005	1005	1005	1005	1005
1006	1006	1006	1006	1006
1007	1007	1007	1007	1007
1008	1008	1008	1008	1008
1009	1009	1009	1009	1009
1010	1010	1010	1010	1010
1011	1011	1011	1011	1011
1012	1012	1012	1012	1012
1013	1013	1013	1013	1013
1014	1014	1014	1014	1014
1015	1015	1015	1015	1015
1016	1016	1016	1016	1016
1017	1017	1017	1017	1017
1018	1018	1018	1018	1018
1019	1019	1019	1019	1019
1020	1020	1020	1020	1020
1021	1021	1021	1021	1021
1022	1022	1022	1022	1022
1023	1023	1023	1023	1023
1024	1024	1024	1024	1024
1025	1025	1025	1025	1025
1026	1026	1026	1026	1026
1027	1027	1027	1027	1027
1028	1028	1028	1028	1028
1029	1029	1029	1029	1029
1030	1030	1030	1030	1030
1031	1031	1031	1031	1031
1032	1032	1032	1032	1032
1033	1033	1033	1033	1033
1034	1034	1034	1034	1034
1035	1035	1035	1035	1035
1036	1036	1036	1036	1036
1037	1037	1037	1037	1037
1038	1038	1038	1038	1038
1039	1039	1039	1039	1039
1040	1040	1040	1040	1040
1041	1041	1041	1041	1041
1042	1042	1042	1042	1042
1043	1043	1043	1043	1043
1044	1044	1044	1044	1044
1045	1045	1045	1045	1045
1046	1046	1046	1046	1046
1047	1047	1047	1047	1047
1048	1048	1048	1048	1048
1049	1049	1049	1049	1049
1050	1050	1050	1050	1050
1051	1051	1051	1051	1051
1052	1052	1052	1052	1052
1053	1053	1053	1053	1053
1054	1054	1054	1054	1054
1055	1055	1055	1055	1055
1056	1056	1056	1056	1056
1057	1057	1057	1057	1057
1058	1058	1058	1058	1058
1059	1059	1059	1059	1059
1060	1060	1060	1060	1060
1061	1061	1061	1061	1061
1062	1062	1062	1062	1062
1063	1063	1063	1063	1063
1064	1064	1064	1064	1064
1065	1065	1065	1065	1065
1066	1066	1066	1066	1066
1067	1067	1067	1067	1067
1068	1068	1068	1068	1068
1069	1069	1069	1069	1069
1070	1070	1070	1070	1070
1071	1071	1071	1071	1071
1072	1072	1072	1072	1072
1073	1073	1073	1073	1073
1074	1074	1074	1074	1074
1075	1075	1075	1075	1075
1076	1076	1076	1076	1076
1077	1077	1077	1077	1077
1078	1078	1078	1078	1078
1079	1079	1079	1079	1079
1080	1080	1080	1080	1080
1081	1081	1081	1081	1081
1082	1082	1082	1082	1082
1083	1083	1083	1083	1083
1084	1084	1084	1084	1084
1085	1085	1085	1085	1085
1086	1086	1086	1086	1086
1087	1087	1087	1087	1087
1088	1088	1088	1088	1088
1089	1089	1089	1089	1089
1090	1090	1090	1090	1090
1091	1091	1091	1091	1091
1092	1092	1092	1092	1092
1093	1093	1093	1093	1093
1094	1094	1094	1094	1094
1095	1095	1095	1095	1095
1096	1096	1096	1096	1096
1097	1097	1097	1097	1097
1098	1098	1098	1098	1098
1099	1099	1099	1099	1099
1100	1100	1100	1100	1100

SPECIMEN NO.13

Material: Copper

Surface Finish: No.1 Paper

Run No.1			Run No.2			Run No.3			Run No.4		
$F_N = 168.2$ lb.			$F_N = 201.3$ lb.			$F_N = 251$ lb.			$F_N = 64.78$ lb.		
Q_A	ψ_s	ψ_{SR}	ψ_s	ψ_{SR}	ψ_s	ψ_{SR}	ψ_s	ψ_{SR}	ψ_s	ψ_{SR}	ψ_s
60	45	--	26	--	--	--	--	--	--	--	--
120	75	7	68	--	54	--	--	--	--	--	--
180	116	9	111	13	--	--	--	--	--	--	--
240	151	10	151	6	95	--	--	--	1	--	--
300	--	--	190	13	--	--	--	--	--	--	--
360			233	12	220	10	--	--	49	--	--
420			255	27	--	--	--	--	--	--	--
480			295	24	292	4	--	--	--	--	--
540			335	25	--	--	--	--	--	--	--
600			380	32	378	16	--	--	--	--	--
660			415	40	--	--	--	--	--	--	--
720			455	38	463	38	--	--	--	--	--
780			498	38	--	--	--	--	--	--	--
840			542	39	546	54	--	--	--	--	--

SPECIMEN NO.13 (continued)

<u>Run No.4</u>	<u>Run No.5</u>	<u>Run No.6</u>	<u>Run No.7</u>	<u>Run No.7</u>
$F_N = 64.78 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$	$F_N = 168.16 \text{ lb.}$	$F_N = 201.29 \text{ lb.}$	$F_N = 201.29 \text{ lb.}$
ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}
120	--	--	--	120
240	2	8	--	240
360	11	7	8	360
480	13	5	15	480
600	16	8	13	600
720	26	17	19	720
840	--	42	28	840
960		63	40	960
1080		81	44	1080
1200		--	48	1200
1320			72	1320
1440			184	1440
1560			246	1560
1680			--	1680
				--

(Benthic) Group 10/12/12

1000.000	1000.000	1000.000	1000.000	1000.000
add 00.100 = 0 ¹	add 00.100 = 0 ¹	add 00.100 = 0 ¹	add 00.100 = 0 ¹	add 00.100 = 0 ¹
000	000	000	000	000
001	001	001	001	001
002	002	002	002	002
003	003	003	003	003
004	004	004	004	004
005	005	005	005	005
006	006	006	006	006
007	007	007	007	007
008	008	008	008	008
009	009	009	009	009
010	010	010	010	010
011	011	011	011	011
012	012	012	012	012
013	013	013	013	013
014	014	014	014	014
015	015	015	015	015
016	016	016	016	016
017	017	017	017	017
018	018	018	018	018
019	019	019	019	019
020	020	020	020	020
021	021	021	021	021
022	022	022	022	022
023	023	023	023	023
024	024	024	024	024
025	025	025	025	025
026	026	026	026	026
027	027	027	027	027
028	028	028	028	028
029	029	029	029	029
030	030	030	030	030
031	031	031	031	031
032	032	032	032	032
033	033	033	033	033
034	034	034	034	034
035	035	035	035	035
036	036	036	036	036
037	037	037	037	037
038	038	038	038	038
039	039	039	039	039
040	040	040	040	040
041	041	041	041	041
042	042	042	042	042
043	043	043	043	043
044	044	044	044	044
045	045	045	045	045
046	046	046	046	046
047	047	047	047	047
048	048	048	048	048
049	049	049	049	049
050	050	050	050	050
051	051	051	051	051
052	052	052	052	052
053	053	053	053	053
054	054	054	054	054
055	055	055	055	055
056	056	056	056	056
057	057	057	057	057
058	058	058	058	058
059	059	059	059	059
060	060	060	060	060
061	061	061	061	061
062	062	062	062	062
063	063	063	063	063
064	064	064	064	064
065	065	065	065	065
066	066	066	066	066
067	067	067	067	067
068	068	068	068	068
069	069	069	069	069
070	070	070	070	070
071	071	071	071	071
072	072	072	072	072
073	073	073	073	073
074	074	074	074	074
075	075	075	075	075
076	076	076	076	076
077	077	077	077	077
078	078	078	078	078
079	079	079	079	079
080	080	080	080	080
081	081	081	081	081
082	082	082	082	082
083	083	083	083	083
084	084	084	084	084
085	085	085	085	085
086	086	086	086	086
087	087	087	087	087
088	088	088	088	088
089	089	089	089	089
090	090	090	090	090
091	091	091	091	091
092	092	092	092	092
093	093	093	093	093
094	094	094	094	094
095	095	095	095	095
096	096	096	096	096
097	097	097	097	097
098	098	098	098	098
099	099	099	099	099
100	100	100	100	100

SPECIMEN NO.14

Material: Copper

Surface Finish: 2/0 Paper

Q_A	<u>Run No.1</u>		<u>Run No.2</u>		<u>Run No.3</u>	
	$F_N = 64.8 \text{ lb.}$		$F_N = 117.4 \text{ lb.}$		$F_N = 168.2 \text{ lb.}$	
	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}	ψ_s	ψ_{sR}
120	73	--	66	--	64	--
240	152	16	136	5	133	--
360	237	26	219	16	205	--
480	341	44	304	33	269	--
600	464	289	393	57	353	5
720	--	--	501	90	431	13
840			521	124	501	15
960			--	294	586	21
1080				873	--	31
1200				--		34
1320						37
1440						64
						--

TABLE NO. 14

Material: Copper

Surface finish: 250 lgrs

Run 1001		Run 1002		Run 1003	
$V = 64.8 \text{ lb.}$		$V = 117.4 \text{ lb.}$		$V = 168.5 \text{ lb.}$	
P	V	P	V	P	V
120	77	—	66	—	84
140	102	10	116	—	111
160	127	20	119	—	120
180	141	30	104	—	126
200	164	40	107	0	131
220	—	50	101	10	131
240	—	60	101	20	131
260	—	70	—	30	131
280	—	80	—	40	131
300	—	90	—	50	131
320	—	100	—	60	131
340	—	110	—	70	131
360	—	120	—	80	131
380	—	130	—	90	131
400	—	140	—	100	131
420	—	150	—	110	131
440	—	160	—	120	131
460	—	170	—	130	131
480	—	180	—	140	131
500	—	190	—	150	131
520	—	200	—	160	131
540	—	210	—	170	131
560	—	220	—	180	131
580	—	230	—	190	131
600	—	240	—	200	131
620	—	250	—	210	131
640	—	260	—	220	131
660	—	270	—	230	131
680	—	280	—	240	131
700	—	290	—	250	131
720	—	300	—	260	131
740	—	310	—	270	131
760	—	320	—	280	131
780	—	330	—	290	131
800	—	340	—	300	131
820	—	350	—	310	131
840	—	360	—	320	131
860	—	370	—	330	131
880	—	380	—	340	131
900	—	390	—	350	131
920	—	400	—	360	131
940	—	410	—	370	131
960	—	420	—	380	131
980	—	430	—	390	131
1000	—	440	—	400	131
1020	—	450	—	410	131
1040	—	460	—	420	131
1060	—	470	—	430	131
1080	—	480	—	440	131
1100	—	490	—	450	131
1120	—	500	—	460	131
1140	—	510	—	470	131
1160	—	520	—	480	131
1180	—	530	—	490	131
1200	—	540	—	500	131
1220	—	550	—	510	131
1240	—	560	—	520	131
1260	—	570	—	530	131
1280	—	580	—	540	131
1300	—	590	—	550	131
1320	—	600	—	560	131
1340	—	610	—	570	131
1360	—	620	—	580	131
1380	—	630	—	590	131
1400	—	640	—	600	131
1420	—	650	—	610	131
1440	—	660	—	620	131
1460	—	670	—	630	131
1480	—	680	—	640	131
1500	—	690	—	650	131
1520	—	700	—	660	131
1540	—	710	—	670	131
1560	—	720	—	680	131
1580	—	730	—	690	131
1600	—	740	—	700	131
1620	—	750	—	710	131
1640	—	760	—	720	131
1660	—	770	—	730	131
1680	—	780	—	740	131
1700	—	790	—	750	131
1720	—	800	—	760	131
1740	—	810	—	770	131
1760	—	820	—	780	131
1780	—	830	—	790	131
1800	—	840	—	800	131
1820	—	850	—	810	131
1840	—	860	—	820	131
1860	—	870	—	830	131
1880	—	880	—	840	131
1900	—	890	—	850	131
1920	—	900	—	860	131
1940	—	910	—	870	131
1960	—	920	—	880	131
1980	—	930	—	890	131
2000	—	940	—	900	131
2020	—	950	—	910	131
2040	—	960	—	920	131
2060	—	970	—	930	131
2080	—	980	—	940	131
2100	—	990	—	950	131
2120	—	1000	—	960	131
2140	—	1010	—	970	131
2160	—	1020	—	980	131
2180	—	1030	—	990	131
2200	—	1040	—	1000	131
2220	—	1050	—	1010	131
2240	—	1060	—	1020	131
2260	—	1070	—	1030	131
2280	—	1080	—	1040	131
2300	—	1090	—	1050	131
2320	—	1100	—	1060	131
2340	—	1110	—	1070	131
2360	—	1120	—	1080	131
2380	—	1130	—	1090	131
2400	—	1140	—	1100	131
2420	—	1150	—	1110	131
2440	—	1160	—	1120	131
2460	—	1170	—	1130	131
2480	—	1180	—	1140	131
2500	—	1190	—	1150	131
2520	—	1200	—	1160	131
2540	—	1210	—	1170	131
2560	—	1220	—	1180	131
2580	—	1230	—	1190	131
2600	—	1240	—	1200	131
2620	—	1250	—	1210	131
2640	—	1260	—	1220	131
2660	—	1270	—	1230	131
2680	—	1280	—	1240	131
2700	—	1290	—	1250	131
2720	—	1300	—	1260	131
2740	—	1310	—	1270	131
2760	—	1320	—	1280	131
2780	—	1330	—	1290	131
2800	—	1340	—	1300	131
2820	—	1350	—	1310	131
2840	—	1360	—	1320	131
2860	—	1370	—	1330	131
2880	—	1380	—	1340	131
2900	—	1390	—	1350	131
2920	—	1400	—	1360	131
2940	—	1410	—	1370	131
2960	—	1420	—	1380	131
2980	—	1430	—	1390	131
3000	—	1440	—	1400	131
3020	—	1450	—	1410	131
3040	—	1460	—	1420	131
3060	—	1470	—	1430	131
3080	—	1480	—	1440	131
3100	—	1490	—	1450	131
3120	—	1500	—	1460	131
3140	—	1510	—	1470	131
3160	—	1520	—	1480	131
3180	—	1530	—	1490	131
3200	—	1540	—	1500	131
3220	—	1550	—	1510	131
3240	—	1560	—	1520	131
3260	—	1570	—	1530	131
3280	—	1580	—	1540	131
3300	—	1590	—	1550	131
3320	—	1600	—	1560	131
3340	—	1610	—	1570	131
3360	—	1620	—	1580	131
3380	—	1630	—	1590	131
3400	—	1640	—	1600	131
3420	—	1650	—	1610	131
3440	—	1660	—	1620	131
3460	—	1670	—	1630	131
3480	—	1680	—	1640	131
3500	—	1690	—	1650	131
3520	—	1700	—	1660	131
3540	—	1710	—	1670	131
3560	—	1720	—	1680	131
3580	—	1730	—	1690	131
3600	—	1740	—	1700	131
3620	—	1750	—	1710	131
3640	—	1760	—	1720	131
3660	—	1770	—	1730	131
3680	—	1780	—	1740	131
3700	—	1790	—	1750	131
3720	—	1800	—	1760	131
3740	—	1810	—	1770	131
3760	—	1820	—	1780	131
3780	—	1830	—	1790	131
3800	—	1840	—	1800	131
3820	—	1850	—	1810	131
3840	—	1860	—	1820	131
3860	—	1870	—	1830	131
3880	—	1880	—	1840	131
3900	—	1890	—	1850	131
3920	—	1900	—	1860	131
3940	—	1910	—	1870	131
3960	—	1920	—	1880	131
3980	—	1930	—	1890	131
4000	—	1940	—	1900	131
4020	—	1950	—	1910	131
4040	—	1960	—	1920	131
4060	—	1970	—	1930	131
4080	—	1980	—	1940	131
4100	—	1990	—	1950	131
4120	—	2000	—	1960	131
4140	—	2010	—	1970	131
4160	—	2020	—	1980	131
4180	—	2030	—	1990	131
4200	—	2040	—	2000	131
4220	—	2050	—	2010	131
4240	—	2060	—	2020	131
4260	—	2070	—	2030	131
4280	—	2080	—	2040	131
4300	—	2090	—	2050	131
4320	—	2100	—	2060	131
4340	—	2110	—	2070	131
4360	—	2120	—	2080	131
4380	—	2130	—	2090	131
4400	—	2140	—	2100	131
4420	—	2150	—	2110	131
4440	—	2160	—	2120	131
4460	—	2170	—	2130	131
4480	—	2180	—	2140	131
4500	—	2190	—	2150	131
4520	—	2200	—	2160	131
4540	—	2210	—	2170	131
4560	—	2220	—	2180	131
4580	—	2230	—	2190	131
4600	—	2240	—	2200	131
4620	—	2250	—	2210	131
4640	—	2260	—	2220	131
4660	—	2270	—	2230	131
4680	—	2280	—	2240	131
4700	—	2290	—	2250	

SPECIMEN NO.14 (continued)

Run No.4 $F_N = 201.3 \text{ lb.}$

Q_A	ψ_B	ψ_{BR}
120	68	--
240	148	16
360	224	23
480	303	38
600	374	48
720	468	63
840	550	67
960	630	79
1080	--	88
1200		95
1320		119
1440		135
1560		178
1680		194
1800		218
1920		258
2040		--

Run No.5 $F_N = 231.68 \text{ lb.}$

Q_A	ψ_B	ψ_{BR}
120	77	--
240	113	14
360	228	28
480	309	37
600	383	43
720	465	54
840	543	66
960	633	85
1080	--	84
1200		96
1320		117
1440		118
1560		139
1680		155
1800		165
1920		180
2040		203
2160		235
2280		261
2400		292
2520		--

(continued) LIST OF RESULTS

Run 1000			Run 1000		
Y = 0.010 10			Y = 0.010 10		
X	Y	Z	X	Y	Z
—	—	100	—	—	100
10	0.10	0.00	10	0.10	0.00
20	0.20	0.00	20	0.20	0.00
30	0.30	0.00	30	0.30	0.00
40	0.40	0.00	40	0.40	0.00
50	0.50	0.00	50	0.50	0.00
60	0.60	0.00	60	0.60	0.00
70	0.70	0.00	70	0.70	0.00
80	0.80	0.00	80	0.80	0.00
90	0.90	0.00	90	0.90	0.00
100	1.00	0.00	100	1.00	0.00
110	1.10	0.00	110	1.10	0.00
120	1.20	0.00	120	1.20	0.00
130	1.30	0.00	130	1.30	0.00
140	1.40	0.00	140	1.40	0.00
150	1.50	0.00	150	1.50	0.00
160	1.60	0.00	160	1.60	0.00
170	1.70	0.00	170	1.70	0.00
180	1.80	0.00	180	1.80	0.00
190	1.90	0.00	190	1.90	0.00
200	2.00	0.00	200	2.00	0.00
210	2.10	0.00	210	2.10	0.00
220	2.20	0.00	220	2.20	0.00
230	2.30	0.00	230	2.30	0.00
240	2.40	0.00	240	2.40	0.00
250	2.50	0.00	250	2.50	0.00
260	2.60	0.00	260	2.60	0.00
270	2.70	0.00	270	2.70	0.00
280	2.80	0.00	280	2.80	0.00
290	2.90	0.00	290	2.90	0.00
300	3.00	0.00	300	3.00	0.00

SPECIMEN NO.15

Material: Copper

Surface Finish: 4/0 Paper

	<u>Run No.1</u>	<u>Run No.2</u>	<u>Run No.3</u>	<u>Run No.4</u>	<u>Run No.5</u>
	$F_N = 201.3 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$	$F_N = 168.2 \text{ lb.}$	$F_N = 117.4 \text{ lb.}$
C_A	ψ_s	ψ_{SR}	ψ_{SR}	ψ_{SR}	ψ_{SR}
120	70	--	--	--	7
240	143	--	--	9	28
360	207	6	--	13	52
480	288	--	2	17	122
600	365	14	11	30	--
720	--	1	13	36	
840		5	20	67	
960		3	--	99	
1080		6		--	
1200		11	17		
1320		22	19		
1440		31	20		
1560		40	27		
1680		57	54		
1800		64	--		
1920		--			

[illegible]

SPECIMEN NO.15 (continued)

Material: Copper

Surface Finish: 4/0 Paper

Run No.6 $F_N = 64.8$ lb.Run No.7 $F_N = 64.8$ lb.

Q_A	ψ_{SR}	ψ_{SR}
120	-9	8
240	2	21
360	33	82
480	--	741
600		--

SPECIMEN NO.16

Material: 2S Aluminum

Surface Finish: No.1 Paper

Run No.1 $F_N = 168.2$ lb.Run No.2 $F_N = 201.3$ lb.

Q_A	ψ_S	ψ_{SR}	ψ_S	ψ_{SR}
12	16	4	--	--
30	36	12	33	--
60	73	12	52	--
90	93	24	90	10
120	126	28	112	12
150	163	37	143	16
180	182	52	172	12
210	215	61	194	18
240	246	55	229	22
270	273	63	260	16
300	301	66	283	32
330	343	71	--	--
360	368	73		
390	395	83		
420	420	86		

01-08-1977

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Wojciech J. G. Tuziak

Издатель: Юридический институт

[illegible][illegible]
$$\text{dL}(\text{C}_{1000}) = 7.1 \cdot 10^{-5} \text{ mol/L}$$
$$-0.16 \pm 0.04$$

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DEFINITION OF SYMBOLS

- A = area (square inches)
 D_i = inside diameter of specimen (inches)
 D_o = outside diameter of specimen (inches)
 E = modulus of elasticity (Young's modulus) (lb./in^2)
 $E_s = G$ = modulus of rigidity (shearing modulus) (lb/in^2)
 F_N = force normal to interface (normal load on specimen)
 (pounds or kilograms)
 L = gage length or length along specimen between indicator
 arms (inches)
 Q_A = applied torque (gram inches)
 R = radius of indicator arm (inches)
 r_m = mean radius of specimen (inches)
 S_N = normal stress at interface (lb/in^2)
 s_n = normal stress at interface (kg/cm^2)
 S_p = principal stress in specimen (lb/in^2)
 S_s = combined shear stress in specimen (lb/in^2)
 S_T = maximum tangential stress in interface due
 to applied torque (lb/in^2)
 s_t = maximum tangential stress in interface (kg/cm^2)
 T_A = torque applied to specimen (lb. inches)
 ψ_c = calculated angle of twist for specimen
 without interface (minutes of arc)
 ψ_o = observed angle of twist in specimen (minutes of arc)
 ψ_R = residual angle of twist in specimen (minutes of arc)
 ψ_s = observed angle of twist in specimen (micrometer drum units)
 ψ_{sR} = residual angle of twist in specimen (micrometer drum units)
 θ_R = apparent slip at interface (centimeters)

1 = Applied force (dynes/cm²)
 2 = Applied force (lb./in.²)
 3 = Applied force (kg./cm.²)
 4 = Applied force (pounds)
 5 = Applied force (tons)
 6 = Applied force (kilograms)
 7 = Applied force (newtons)
 8 = Applied force (milligrams)
 9 = Applied force (micrograms)
 10 = Applied force (nanograms)
 11 = Applied force (picograms)
 12 = Applied force (femtograms)
 13 = Applied force (attograms)
 14 = Applied force (zeptograms)
 15 = Applied force (yoctograms)
 16 = Applied force (rattograms)
 17 = Applied force (quectograms)
 18 = Applied force (picohectograms)
 19 = Applied force (femtohectograms)
 20 = Applied force (attohectograms)
 21 = Applied force (zeptohectograms)
 22 = Applied force (yoctohectograms)
 23 = Applied force (rattohectograms)
 24 = Applied force (quattohectograms)
 25 = Applied force (pentohectograms)
 26 = Applied force (hexahectograms)
 27 = Applied force (hectohectograms)
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 100 = Applied force (petahectograms)

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